MODELLING ENERGY INPUTS, OUTPUTS AND CONSUMPTION PATTERNS OF SELECTED CROPS IN NIGERIA

BY

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CERTIFICATION

This is to certify that this work was carried out by **KOSEMANI, Babajide Saheed** under my supervision in the Department of Agricultural and Environmental Engineering, Faculty of Technology, University of Ibadan.

……………………………………………………………………

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DEDICATION

This project report is dedicated to the Great God of the universe and to my beloved parents.

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ABSTRACT

Energy consumption in agriculture has increased year by year while more intensive energy use has led to some environmental problems such as natural resources depletion and climate change. Such problems can be ameliorated by effective use of energy resources in crop production.However, in Nigeria, there is scarcity of information on energy expenditure and returns in crop production. This study was designed to determine the energy inputs and consumption patterns of three common staple crops: (rice, maize and yam) in Nigeria.

The study was undertaken across five states: Ondo and Ekiti for rice; Oyo and Ogun for maize and Benue for yam production. For each crop, nine established farms were purposively selected and categorised into small (< 2 ha), medium (2 - 10 ha) and large (> 10 ha) farms. Energy inputs in the production of each crop for 2012 and 2013 growing seasons were investigated based on unit operations. Energy related data such as human labour (x_1), fuel (x_2), machinery (x_3), biological (x_4), N.P.K fertiliser (x_5, x_6, x_7) and herbicide (x_8) were obtained through field surveys, direct measurements, interviews with farmers and structured questionnaires. Efficiencies of energy utilised were determined using standard methods. The relationship between the different input and output energy sources were modelled using Cobb-Douglas production function and validated following Durbin-Watson procedure. Data were analysed using ANOVA at $\alpha_{0.05}$.

Total energy input for rice production on small, medium and large farms were 15107.39±106.0, 14842.52±164.0 and 14396.62±61.9 MJ/ha, respectively. The corresponding energy inputs for maize production were 10084.5±42.0, 9999.5±148.1, 9445.87±36.0 MJ/ha and yam production were 19895.0±67.0, 19392.1±61.5, 19024.3±40.2 MJ/ha, respectively. The net energy for rice production were 81838.11±4046.9, 90693.2±2975.4, 93854.14±1751.9 MJ/ha and for maize production were 30977.45± 1153.6, 39564.0±460.3, 40558.4±1133.7 MJ/ha and yam production were 37535.7±1725.7, 39814.9±919.8, 41209.1±1597.3 MJ/ha on small, medium and large farms, respectively. The average energy efficiencies for rice production on small, medium and large farms were 7.5±0.2, 7.2±0.1 and 7.7±0.1, respectively. The corresponding maize and yam production average efficiencies were 4.0±0.1, 4.9±0.1, 5.2±0.1 and 2.9±0, 3.0±1, 3.5±0, respectively, indicating that energy were efficiently utilised. For rice production, chemical energy accounted for 72.2±0.8, 73.6±0.9 and 75.14±1.6% of the total energy consumed on small, medium and large farms, respectively. Chemical energy constituted 49.4±0.7, 49.6±0.3, 48.34±0.2% in maize production and constituted 48.99±0.9, 48.38±0.1, 48.0±0.1% in yam production. The model equations for rice, maize and yam production were: $\ln y_i = 0.02684 ln x_1 + 0.05082 ln x_2 + 0.08157 ln x_3 + 0.13891 ln x_4 + 0.86125 x_5 + 0.44623 ln x_6 - 0.64041 ln x_7 + 0.00344 ln x_8$ (R^2 = 0.98), $\ln y_i = 0.59171 ln x_1 - 2.14991 ln x_2 + 6.72003 ln x_3 - 0.84842 ln x_4 - 2.50803 \ln x_5 + 0.17059 ln x_6 + 0.12608 ln x_7 + 0.05759 ln x_8$ ($R^2 = 0.98$)and $\ln y_i =$

$- 0.14937 ln x_1 + 0.08818 ln x_2 + 0.15034 ln x_3 + 0.16875 ln x_4 + 0.03868 ln x_5 + 0.6038 ln x_6 - 0.11359 ln x_7 + 0.59838 ln x_8$ ($R^2 = 0.98$), respectively. The energy resources thatare significant for rice production were chemical, biological, manual, and mechanical energy. The corresponding energy resources that are significant for maize and yam production were manual, thermal, mechanical, chemical energy and chemical, thermal, and manual energy, respectively. The results obtained from Durbin-Watson procedure showed that the developed models were capable of predicting energy output at different inputs.

Energy inputs and patterns of energy consumption in rice, maize and yam production were modelled. The models adequately predicted the input and output energies for the selected crops.

Keywords: Crop production, Crop energy utilisation, Energy efficiency, Energy model
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ABBREVATIONS

MJ: Mega Joule

kW: kilo Watt

S/N: Serial number

hr: hour

hp: horse power

C: Celsius

Ha: Hectare

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CHAPTER ONE
INTRODUCTION

1.1 General Background

Agriculture is both a producer and consumer of energy. It uses large quantities of locally available non-commercial energy, such as seed, manure and animate energy, as well as commercial energies, directly and indirectly, in the form of diesel, electricity, fertilizer, plant protection, chemical, irrigation water, machinery etc.(Singh *et al*., 2002). In agro-ecosystems, energy requirements are classified into four groups: direct and indirect, renewable and non-renewable. Direct energy is required to perform many tasks such as land preparation; irrigation, threshing, harvesting and transportation of agricultural inputs and farm products (Singh, 2000). Indirect energy contains the energy consumed in constructing, packaging and carrying fertilizers, biocides and machinery (Ozkan *et al.,* 2004). Non-renewable energy includes diesel, chemicals, fertilizers and machinery, and renewable energy consists of human labor, water, seeds and farmyard (Mohammadi *et al.,* 2008).

Energy consumption in agriculture has been increasing in response to increasing population, limited supply of arable land, and a desire for higher standards of living (Kizilaslan, 2009), while more intensive energy use has led to some important human health and environmental problems.Today's agricultural production relies greatly on the consumption of non-renewable energies such as fossil fuel. Consumption of fossil energy results in direct negative environmental effects through release of CO_2 and other burning gases (Gallaher *et al.,* 2009). Nevertheless, great amounts of inexpensive fossil energy have indirect negative impacts on the environment such as less diversified nature etc. Energy, economics, and the environment are commonly dependent together (Refsgaard *et al.,* 1998; Pimentel *et al.,* 1994). It is necessary to reduce fossil energy inputs in agricultural systems, so as to help reduce agricultural carbon dioxide emissions.

In modern agriculture system input energy is very much higher than in traditional agriculture system, but energy use efficiency has been reduced in response to no effective use of input energy (Mobtaker*et al,* 2012).The productivity and profitability of agriculture depend upon energy consumption at the present. Thus, looking for agricultural production methods with higher energy productivity is today as typical as it was some 20 years ago (Refsgaard *et al.,*1998).Sufficient availability of the right energy and its effective and efficient use are prerequisites for improved agricultural production. It helps to achieve increased production and productivity and contributes to the profitability and competitiveness of agriculture sustainability in rural living (Singh *et al*., 2002). It has been realised that crop yields and food supplies are directly linked to energy availability or consumption. Also, increases in yields and acreage in the developed countries were as a result of commercial energy inputs, in addition to improved varieties.

The enhancement of energy efficiency production system will notonly helps in improving competitiveness through cost reduction but also results in minimized energy-related environmental problems, prevent destruction of natural resources, and support sustainable agriculture as an economical production system (Erdal *et al.,* 2007; Nagesha, 2008). Efficient use of energy in agriculture will reduce environmental. It will helps to achieve increased productivity and contributes to the economy, profitability and competitiveness of agriculture sustainability in rural areas (Ozkan *et al*., 2004; Singh *et al*., 2002). Thus, efficient use of energy inputs has become important in terms of sustainable farming (Karimi *et al.,* 2008), and is one of the principal requirements of sustainableagriculture.

Energy input–output analysis is usually used to evaluate the efficiency and environmental impacts of production systems for agricultural sustainability (Lorzadeh *et al*., 2012. It is also used to compare the different production systems.

1.2 Justification of the Study

Energy is one of the largest components of the production cost and the efficiency of its use will often be compromised in favour of other equally important factors. The need for such great attention to energy management has been highlighted by several published research of energy use in agricultural processing operations. Reported literature on energy expenditure in crop cultivation and processing include; plantain production in Nigeria (Jekayinfa*et al*., 2012), Field crops in Turkey (Canakci *et al.,* 2005) maize cultivation (Banaeian and Zanggeneh, 2011, Lorzadeh *et al*., 2011) and tangerine production in Iran (Mohammadshirazi *et al*., 2012),palm kernel oil processing (Jekayinfa, and Bamgboye, 2006), cashew-nut processing (Jekayinfa, and Bamgboye, 2006, rice processing (Verma, 2002),

Chemical fertilizers, pesticides, agricultural machinery, and other farm inputs are used extensively in modern agriculture. Efficient use of energy inputs in agriculture will reduce environmental impacts, prevent damage to natural resources, and improve the sustainability of agriculture as an economical production system (Kizilaslan, 2008). For example, reducing the energy derived from fossil fuels within agricultural systems has important implications for decreasing atmospheric emissions of greenhouse gases, thus assisting the mitigation of global warming. The identification of crop production methods, which maximize energy efficiency and minimize greenhouse gas emissions, is vital (Tzilivakis et al., 2005).

Efficient use of energy resources will helps to achieve increased production, improve productivity and contribute to economy, profitabilityand competitiveness of agriculture sustainability to rural living (Singh *et al*., 2002. Therefore, energy saving has been a crucial issue for sustainable development in agricultural systems. Development of energy efficient agricultural systems with low input energy compared to the output of food can reduces greenhouse gas emissions, provides financial savings, fossil fuels preservation and air pollution reduction from agricultural production systems(Pervanchon, 2002).

Scientific forecasts and analysis of energy consumption will be of great importance for the planning of energy strategies and policies (Lianga *et al*., 2007). The accurate prediction of energy consumed in crop production and other processing units is necessary to minimize costs, to achieve more consistent product quality, and to manage different processes, which can be carried out using Cobb-Douglas production function. The Cobb-Douglas production function model can predict energy consumption in rice, maize and yam production under different conditions. Using several crucial input variables would improve the flexibility of the model and help farmers, scientists, and decision makers compare energy efficiencies in different farming systems under different farming conditions.

Currently in Nigeria, there is lack of information on energy expenditure and returns on crop production (Abubakar and Ahmed, 2010). Therefore, research with the aim of increasing the efficient use of these energy resources should be arranged.

1.3 Objectives of the Study

This study was designed to determine the energy inputs, outputand consumption patterns during cultivation, handling and processing of three common staple crops: (rice, maize and yam) in Nigeria.

The specific objectives of this study are to:

i. Estimate various sources of energy used in the production of rice, maize and yam.
ii. Identify the energy use patterns for the cultivation and processing of the crops.
iii. Analyze energy flow, measure farm-level energy efficiency and makes an economic analysis of rice, maize and yam production.
iv. Develop models relating different input and output energy sources in rice, maize and yam cultivation using Cobb-Douglas production function.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Agricultural Production in Nigeria

Agriculture is the main stay of Nigerian economy. It involves small scale farmers scattered over wide expanse of land area, with small holding ranging from 0.5 to 3.0 hectare per farm land. It is characterized by rudimentary farm systems, low capitalization and low yield per hectare (Kolawale and Ojo, 2007). The roles of agriculture remain significant in the Nigeria economy despite the strategic importance of the oil sector. Agriculture provides primary means of employment for Nigeria and accounts for more than one third of total gross domestic product (GDP) and labour force (Babatunde and Oyatode, 2005). Cereal, root, and tuber dominate Nigerian crop production. The most common cereal is the sorghum (guinea corn), which is grown mainly in the northern states. Rice is ranked as the sixth major crop in terms of the land area while sorghum account for 50% of the total cereal production and occupies about 45% of the total land area devoted to cereal production in Nigeria (national extension agricultural research and liaison station (NEARLS, 1996). About 28 percent of farmers grow sorghum and 21 percent grow cassava. Cassava contributes the largest share of daily per capita food consumption (1.6 kg) in Nigeria and is grown in the north and south(FAOSTAT, 2003). Nigeria is the world's largest producer of cassava, though the crop is grown largely for the domestic and regional markets. Nigeria is also the world's largest producer and consumer of yams. In 2004, Nigeria accounted for 70 percent of the 47 million tons of yam produced in the world. Nigeria is also the world's leading producer of cowpea (Manyong *et al*., 2005).

Interestingly, a larger share (40 percent) of farmers in the richest quintile grow cassava compared with only 11 percent in the poorest quintile. About 8 percent to 11 percent of farmers are also reported to grow beans, yams, maize and millet. However, Maziya-Nixon, (2004) reported that maize is the most frequently consumed crop. FAOSTAT (2003) shows that the cereal is the ninth-most important contributor to daily food consumption in Nigeria.

The importance of maize has been increasing reducing the dominance of the tuber crops in Nigerians' diets. Rice is the third-most frequently consumed crop in households (Maziya-Dixon *et al.,* 2004) but it is only the sixth-most important contributor to daily per capita consumption of food. Due to its increasing importance as a food crop especially to the urban population, the government has designed a number of strategies to reduce the importation of rice. Maize is also among the presidential initiative crops.

The limited number of farmers who reported growing export crops like cocoa, cotton, rubber, oil palm, and ground nuts is noteworthy. As is the case in other African countries, commercial crop farmers are the richest farmers in Nigeria (Ojowu *et al.,* 2007). Only 2.3 percent of farmers reported growing cocoa and less than1 percent grew cotton. This underscores the domestic orientation of Nigeria's agricultural production. Such an orientation is justified by the large urban market in Nigeria, which is one of the most urbanized countries in Sub Saraham Africa (SSA).

However, the need to increase production of export crops is also critical given the country's high agricultural potential and the number of poor Nigerians who depend on the agricultural sector.

2.2 Cereal Crop

Cereals are those members of the grass family, the Poeceace grown for their characteristic fruit, the caryopsis, which have been the most important sources of world's food for the last 10,000 years (Onwueme and Sinha, 1991). Wheat and barley are the oldest cultivated cereals. Their cultivation started in the fertile crescent of Mesopotamia some 10,000 years ago, this region now include parts of Turkey, Syria, Iraq and Iran (Onwueme and Sinha, 1991).

The major cereal crops in Nigeria are rice, maize, sorghum, wheat, pearl, millet and sugar cane with rice ranking as the sixth major crop in terms of the land area while sorghum account for 50% of the total cereal production and occupies about 45% of the total land area devoted to cereal production in Nigeria (national extension agricultural research and liaison station (NEARLS, 1996).The role of cereals to modern society is related to its importance as food crop throughout the world. In most parts of Asia and Africa, cereals products comprise 80% or more of the average diet, in central and western Europe, as much as 50% and in the United State, between 20 - 25% (Onwueme and Sinha, 1991).

Cereals are the major dietary energy suppliers and provide significant amount of protein, minerals (potassium and calcium) and vitamins (vitamin A and C) (Idem and Showemimo, 2004). Cereals are consumed in a variety of forms, including pastes, noodles, cakes, breads, drinks etc. depending on the ethnic or religious affiliation. The bran, husk, plant parts and other residues (after processing) are useful as animal feeds and in the culture of micro-organism. Wax syrup and gum are extracted from cereals for industrial purposes. Different Nigeria ethnic groups use cereal crops residues for different purposes.

More than 70% of the working adult populations in Nigeria are employed in the agricultural sector directly or indirectly and over 90% of Nigeria's agricultural output comes from peasant farmers who dwell in the rural areas where 60% of the population live. The vast majority of these farmers who have limited access to modern inputs and other productive resources are also unlikely to have access to pesticides, fertilizers, hybrid seeds and irrigation without some form of public sector intervention (Ogunwole *et al.,* 2004). Some of major problems militating cereals production in Nigeria are climatic factors (rainfall, temperature and solar radiation), soil factors, migration, socioeconomic considerations and government policies, pests and diseases among others.

2.3 Rice Production

Rice is one of man's oldest food items. It provides the principal food for about half of the world's population next to wheat (Eleanor, 1975; Chandler, 1979). Rice constitutes one of the major crops produced in Nigeria. Babafada (2003) asserted that rice is the forth major cereal in Nigeria after sorghum, millet and maize in terms of output and cultivated land area. It is a major staple and most popular cereal crop of high nutritional value grown and consumed in all ecological zones of the country.

Rice provides 21% of global human per capita energy and 15% of per capita protein. It is low in fat and protein, compared with other cereal grains. Recent studies by the modern nutritionists have compared the easily digestible organic rice protein, a highly digestible and non-allergenic protein to mother's breast milk in the aspect of its nutritious quality and also for the high quantity of amino acid that is common in both rice protein and breast milk.Since the mid-1980's, rice consumption has increased at an average annual rate of 11% with only 3% explained by population growth (Erhabor and Ojogho,2011). Also, within the decade of the 1990's, Erenstein *et al.* (2004)reported a 14% annual increase in the demand for rice in Nigeria. The average Nigerian now consumes about 24.8 kg of rice per year representing 9% of the total calories intake. In spite of its contribution to the food requirements of the Nigerian population, rice production in the country is put at about 3.2 million tonnes (Babafada, 2003). This has been shown to be far below the national requirement as over $600 million worth of rice is annually being imported into the country (Adeoye, 2003).

The agricultural and industrial uses of rice include the use of rice straw and bran as cattle feed and as a growing medium for mushrooms; use of rice husks and hulls as a seedbed medium; use of bran for extraction of a healthful oil; and use of rice for making rice beer and rice-based wine. Only 5 per cent of the total global production of rice enters international trade. Thus, for many countries national self-sufficiency in rice production is a crucial matter.

The cultivation of rice has been practised in many countries for over 6 500 years. Dryland rice culture preceded the adoption of wetland paddy culture. Two species of the rice genus have been domesticated: *Oryza sativa* and *Oryza glaberrima*. The former is widely cultivated and originated in the foothills of the Himalayas, while the latter, limited to Africa, originated in the Niger River delta. Rice is grown from about 50° N to 35° S and from below sea level to above 2 000 m, covering a mean temperature range of 17°C to 33°C, a growing-season rainfall range of 0 to 5 100 mm, and a solar radiation range of 300 to 600 calories/cm_2/day in the various growing areas and different seasons. Many of the rice-growing areas are served by major rivers and have alternating wet and dry seasons. The varieties used and cultural practices adopted in rice cultivation vary widely and are influenced by local climatology (rainfall, temperature and solar radiation regimes) and times and certainty of availability of water for main or supplementary surface irrigation. The variations in cultural practices may not, per seed, affect the phenological or physiological responses of the crop to weather factors. The water, fertilizer and seed requirements of the crop, its field-life duration, extent of realization of potential yields, and susceptibility to pests, diseases and weeds are affected by cultural practices, however. The unravelling of the relationship between weather and various aspects of growth, development, yield and protection of rice crops is, therefore, complex. Data on rice production in acreages and per capita consumption for 29 countries that produce more than one million tonnes of the total 620 million tonnes of global rice production, are as shown in Table 1. The 29 countries in the list account for about 580 million tonnes, with an average yield of 3.9 tonnes per hectare (t/ha).

Nearly 90 per cent of the rice is produced in Asia. China and India account for 30 per cent and 20 per cent of global production, and 20 per cent and 30 per cent of the global cultivation area, respectively. The South-East Asian region extending from Pakistan to Indonesia and comprising 12 countries accounts for 60 per cent and 70 per cent, respectively, of the global area and production. In this region, rice yield averages 3.5 t/ha, with Indonesia and Viet Nam producing 4.5 t/ha and Cambodia and Thailand producing 2 t/ha and 2.5 t/ha, respectively. The yields in Egypt and Australia are 10 t/ha and 8 t/ha, respectively, while the yield in China, Italy, Japan and the Republic of Korea is in the range of 6 to 7 t/ha. Thus, a poleward increase in rice yields is discernible. The yields in African regions are very low and range from 1 to 2 t/ha.

Both the South-East and East Asian regions regularly experience cyclonic storms/typhoons, are subject to riverine floods, and are characterized by heavy rains of 100 mm per week or so over an extended period. Rice is the only suitable crop that can be grown under puddled soil conditions, that is, with standing water over bunded fields. In fact, certain varieties of rice, called floating rice, have the ability to elongate their stems with a rise in water level up to a height of 2 m and remain alive for a fortnight even when water levels reach a height of 6 m. The low yield in the South-East and East Asian regions is due to the preponderance of rainfed areas, which also leads to great interannual variability in out-turns.

Plate 1: ARice Farm

Table 1: Rice production and consumption statistics worldwide

Country	Production (000 tonnes)	Area (000 ha)	Yield (t/ha)	Consumption (kg/capital/year)
China	176 342	28 509	6.19	83
India	116 500	40 280	2.89	83
Indonesia	51 490	11 521	4.47	149
Bangladesh	37 593	10 771	3.49	164
Viet Nam	34 447	7 504	4.59	169
Thailand	26 057	9 988	2.61	103
Myanmar	21 805	6 381	3.42	205
Philippines	13 271	4 046	3.82	105
Japan	11 111	1 688	6.58	58
Brazil	10 457	3 146	3.32	35
United states	9 569	1 298	7.37	9
Pakistan	6 718	2 225	3.02	18
Korea rep	6 687	1 053	6.35	83
Egypt	6 105	613	9.97	38
Nepal	4 133	1 545	2.69	102
Cambodia	3 823	1995	1.92	149
Nigeria	3 192	3 160	1.01	24
Iran	2 888	611	4.73	37
Sri lanka	2 859	820	3.49	91
Madagascar	2 604	1 216	2.14	95
Laos	2 417	783	3.09	168
Colombia	2 348	469	5.01	30
Malaysia	2 197	677	3.25	73
Korea, DPR	2 186	583	3.75	70
Puru	2 119	317	6.69	49
Italy	1 379	219	6.31	6
Ecuador	1 285	327	3.93	47
Australia	1 192	150	7.95	10
Cote d' Ivoire	1 080	470	2.30	63
World	577 971	147 633	3.91	57

Yield = Total production/total area and an average across all rice environments and seasons

Source: FAO,2002

2.4 MAIZE PRODUCTION

Maize is the world's third most important crop after rice and wheat. About half of this is grown in developing countries, where maize flour is a staple food for poor people and maize stalks provide dry-season feed for farm animals. Diversified uses of maize worldwide include: maize grain; starch products; corn oil; baby foods; popcorn; maize-based food items; maize flour; forage for animals; maize stalks providing dry-season feed for farm animals; maize silage for winter animal feed in cold temperate regions; and maize stalks as a soil mulch where it is in abundance. Maize grain is used as feed for beef, dairy, hog and poultry operations in developed countries. Maize can be classified on the basis of its protein content and hardness of the kernel. Varieties include popcorn and flint, flour, Indian and sweet corn.

In industrialized countries maize is largely used as livestock feed and as raw material for industrial products; for instance, in Australia it is used for feed, silage, breakfast food and processing (breakfast cereals, corn chips, grits and flour), industrial starch and popcorn. In low-income countries it is mainly used for human consumption.

In sub-Saharan Africa, maize is a staple food for an estimated 50 per cent of the population and provides 50 per cent of the basic calories. It is an important source of carbohydrate, protein, iron, vitamin B and minerals. Africans consume maize as a starchy base in a wide variety of porridges, pastes, grits and beer. Green maize (fresh on the cob) is eaten parched, baked, roasted or boiled and plays an important role in filling the hunger gap after the dry season. The yields are low, however, fluctuating around 1.0 tonne per hectare (t/ha). Several African countries have focused attention on increasing maize production in the smallholding agricultural sectors, but such efforts have been ineffective because of heavy pre- and post-harvest losses caused by diseases, weeds and pests. In South Africa, in addition to the traditional uses, the country is considering maize fuel, an alcohol-based alternative fuel produced by fermenting and distilling the starch-rich grains of the crop.

According to United Nations Food and Agriculture Organization (FAO), maize yields currently average 1.5 t/ha in Africa, slightly more than 3 t/ha in Latin America and 1.7 t/ha in India. FAO indicates that grain yields have been recorded as follows: 5–6 t/ha (dryland) and 8–10 t/ha (irrigated). For silage, at 68–70 per cent moisture content, yields of 20 t/ha (dryland) and 42 t/ha (irrigated) have been recorded.

In the developing world, most farmers have to accept low yields, as they are unable to consider the use of improved production methods because they operate at small-scale subsistence levels. Yield gap analyses will draw farmers' attention to lost production potential under the prevailing climatic conditions in their respective environments and which production practices (soil fertility, agronomic measures, cultivar selection, and the like) need to be improved. Yield differences among regions should provide the incentive to manoeuvre toward yield improvement. (Yield potential refers to the highest yield achievable on farmers' fields – with the use of improved seed (high yield, tolerance to diseases and pests), appropriate levels of nutrients, water and weed control).

According to *Ofori et al.,* (2004), the difference between the actual and potential yield of a typical maize variety grown during the major cropping season (April through July) on a farm in Ghana over a nine-year period was just over 4 t/ha (that is, the actual yield varied from 0.9 to 1.4 t/ha and the potential for that season should have been 5.5 t/ha). The April–July rainfall varied from 570 to 790 mm over this nine-year period.

In the tropics and subtropics, small-scale farmers grow most of the maize, generally for subsistence as part of agricultural systems that feature several crops and sometimes livestock production. The system often lacks inputs such as fertilizer, improved Seed, irrigation and labour. In most developing countries there is very little purchased input for the cropping system and it essentially depends on the natural resource base. The soil nutrients in the natural resource base are dwindling faster than they are being replaced. Rainfall is the single most important natural resource input under this form of cropping. Increasing population pressure has resulted in an intensification of land use. Nutrients and organic matter in the soil have been depleted and crop yields have steadily decreased. To increase production it will be necessary to replenish soil nutrients and optimize the use of other resources such as seed, water, capital and labour. Land-use intensification is only feasible if nutrients depleted during cultivation are replenished. Inorganic fertilizer use in sub-Saharan Africa is generally limited by the lack of financial resources for the farmers.

Plate 2: A Maize Farm

2.5 YAM PRODUCTION

Yams belong to the family *Dioscoreaceae* and are members of the genus *Dioscorea*, which produce tubers and bulbils that are economically important. The genus *Dioscorea* is by far the largest genus of the family and is very important throughout coastal West Africa where approximately 60 million people obtain more huge calories of energy of about 800KJ day-1 from it. Food yams are predominantly cultivated in the humid forest, forest/savanna transition and the southern guinea savanna (SGS) zones of West Africa. Large percentages of current production are in the southern guinea savanna SGS zones.Nigeria is by far the world's largest producer of yams, accounting for over 70–76 percent of the world production (Wikipedia, 2011). According to the Food and Agricultural Organization report, in 1985, Nigeria produced 18.3 million tonnes of yam from 1.5 million hectares, representing 73.8 percent of total yam production in Africa. According to 2008 figures, yam production in Nigeria has nearly doubled since 1985, with Nigeria producing 35.017 million metric tonnes with value equivalent of US$5.654 billion. Also in West Africa, average statistics has shown that 95% of the world's output of 34 million metric tonnes (mmt) of yam in 2001was produced and Nigeria alone produced 75% of this total Output.(Wikipedia, 2011).

In perspective, the world's second and third largest producers of yams, Cote d'Ivoire and Ghana, only produced 6.9 and 4.8 metric tonnes of yam in 2008 respectively. According to the International Institute of Tropical Agriculture, Nigeria accounted for about 70 percent of the world production, amounting to 17 million tonnes from land area of 2,837,000 hectares under yam cultivation. (Wikipedia, 2011).

Average daily consumption per capita is highest in Benin Republic (364 kcal), Cote d'lvoire (342 kcal), Ghana (296 kcal) and Nigeria (258 kcal). However, the major producers of yam in Nigeria are Niger State, Abia State, Taraba State, Nassarawa State and Benue State. (Wikipedia, 2011).

2.5.1 YAM VARIETIES

Yam, a tropical crop of the genus *Dioscorea* has as many as 600 species out of which five are economically staple species. These areWhite yam(*Dioscorea rotundata*),Chinese yam Dioscorea esculenta),Water yam(*Dioscorea alata*), Aerial yam(*Dioscorea bulbifera)* and Trifoliate yam (*Dioscorea dumentorum*). Out of these*,*White yam*(Dioscorea rotundata)* and Water yam(*Dioscorea alata*) are the most common species in Nigeria.

(i) **White yam (D. *rotundata*)**: this is the best quality yam for eating. Its tubers are usually large, but vary in size, and shape. The colour of the flesh is always white to cream. It matures eight months after planting and stores well.

(ii) **Yellow yam (D. *cayenensis*)**: The flesh of this variety is yellow. The leaves are thick, broadly heart-shaped with dents near the stalk. They are dark, glossy green in colour. It matures in twelve months and does not store well.

(iii) **Water yam (D. *alata*):** This is the only yam grown in West Africa with petioles. The leaves are large and broad. The tubers are large with soft texture and high water content. The flesh is yellow or purple. It has a poorer storing quality than white or yellow yam. It matures in ten months. In Nigeria it is used to make *ikokore* and *ojojo*

(iv) **Chinese yam (D. *esculenta*):** This yam has pale, broad, heart-shaped leaves and grows best in drier and open districts. It produces very many small tubers in a hill.The tubers have a pale-yellow, smooth skin which bruises easily. Because of this, the yam does not store well. This yam matures twelve months after planting.

(v) **Aerial yam. (D. *bulbifcra)*:** This yam bears tubers both on the vines and underground. The tubers have strong corky skins which enable them to store well for long periods. Two or more types are edible but they are not widely grown.

(vi) **Three-leafed yam (D. *dummtonm)*:** This has prickly leaves which climb clockwise.

The tubers are large, and the bark is coarse. The flesh is finegrained, yellow, white or pink in colour.

2.5.2 Economic Importance of Yam.

Yam being an important staple food for about 60 million people in West Africa, it is necessary to lower its production cost and scale up its production through efficient use of its production resources.Yam is a highly valued food in Nigeria with the bulk of it consumed boiled or pounded.

The contribution of yams to the dietary needs of man and economic gains accrue from its cultivation cannot be over emphasized. Carbohydrate is derived from yams and it is a good source of energy needed for the day activities of most Nigerians and contributes about 20% of the daily calorie in- take in the diet (Iwueke, 1989).

Yams are usually made into various food items, recipes and confectionary according to individual's preference or needs. It is a good source of energy 100g of yam provides 118 calories. It is mainly composed of complex carbohydrates and soluble dietary fibre. Together, they raise blood sugar levels rather very slowly than simple sugars, and therefore, recommended as low Glycemic Index (GI) healthy food, also known as low GI food. Low GI foods helps to increase energy level and lose weight, and they also improve blood glucose control for people with diabetes. In addition, dietary fibre helps reduce constipation, decrease cholesterol levels by binding to it the intestines and prevent colon cancer risks by preventing toxic compounds in the food. It is an excellent source of B-complex groups of vitamins. It is indeed one of the vegetable rich sources of minerals like copper, manganese, calcium, potassium and phosphorus. Yam also has an important social status in gatherings and religious functions, which is assessed by the size of yam holdings one possesses.

Besides, yam growers could make an important contribution to the national food supply, where a healthy and expanding market food crop industry is a safeguard against the lowering of health standards necessary for productive output in an expanding economy like ours (FAO, 2011).

Plate 3: AYam Farm

2.6 Energy

For the Greeks, the word *energein* meant to act, work, produce, and change. The standard definition of energy in physics and mechanics is the capability to do work, as introduced by Thomas Young in his 1805 Bakerian Lecture to the Royal Society (Boyle, 2004; Pimentel & Pimentel, 2008; Tester, 2005). Work can be defined as the product of the force needed to move object times the distance that it moves (Randolph & Masters, 2008).

Sometimes the word ―power‖ is used as a synonym for energy; nonetheless, power is defined as the rate of doing work. The main unit of energy is the joule (J) and the main unit of power is the watt (W), which is defined as the rate of one joule per second (Boyle, 2004). The Joule is a new and SI unit (International System of Units) of energy; previously, the calorie was the common unit of energy. One J is the force of one Newton (mass of one kg accelerated by one m/s^2) acting over a distance of one metre (this definition covers only kinetic energy). The calorie is a non-SI unit of thermal energy. It is defined as the amount of heat needed to increase the temperature of one g of water from 14.5º C to 15.5º C (Smil, 2008; Tester, 2005). It is possible to convert these units to each other: 1 cal= 4.1855 J.

There is a standard classification of energy forms in mechanics, named kinetic energy and potential energy. It is also possible to categorize energy into energy types, such as chemical energy, muscular energy, mechanical energy, and electrical energy. However, as for importance, energy is classified as energy resources: fossil fuel and renewable energy. Fossil fuel energy resources include oil, natural gas, and coal, and renewable energy resources include solar energy, wind, bio-energy, tidal, hydro, and geothermal energy. It is important to note that some types of energy sources are more suitable for mechanical work.

2.7 Energy Resources

People rely on various sources of energy and power. These sources range from human, animal, wind, tidal, and water energy to wood, coal, gas, oil, solar, and nuclear sources of fuel and power. Using fossil fuel resources enables a nation to feed an increasing number of humans, and improves the general quality of life in many ways, including protection from malnourishment and numerous other diseases.

About 473 quads (1 quad = 1015 BTU = 1.05 x 1018 Joules) from fossil and renewable energy sources are used worldwide per year. The current high rate of energy expenditure is related directly to many factors, including rapid population growth, urbanization, and high resource-consumption rates. Increased energy use also contributes to environmental degradation. Energy use has been growing at a rate even faster than the rate of growth of the world population. From 1970 to 1995, energy use has been doubling every 30 years whereas the world population has been doubling every 40- 0 years. In the near future, energy use is projected to double every 32 years while the population is projected to double in about 50 - 60 years.

About 60% of all the solar energy captured by photosynthesis and incorporated in biomass production worldwide is used by humans (Pimentel, unpublished data). This amount of energy, though very large (approximately 720 quads), is inadequate to meet human needs. To compensate for the high demand, about 413 quads of fossil energy (oil, gas, and coal) are utilized each year worldwide.

2 .8 Need for Energy and Use

Mankind is using energy in many ways to improve its living standards. The world's energy consumption is increasing, which is related to growing population and consumption. Energy consumption is predicted to increase from 497EJ in 2006 to 715 EJ in 2030. This 44% increase is leading to GHG emission (Cherubini and stronmman, 2010). Cherubini and stronmman (2011) estimate that a bio- energy supply 10% of the total world primary energy, which is not most cases is used in the resident for domestic purpose like heating and cooking. Energy is important because it is also correlated with gross products, labour productivity and price levels (Cleveland *et al.*, 1984), which shows that energy is the driving force to economic development.

2.9 Energy and Agriculture

Agriculture is both a consumer and a producer of energy. Modern agriculture started through the domestication of fruits, nuts and grains (DeGregori, 2001). Agriculture is an energy conversion process. It converts two naturally abundant materials, water and carbon dioxide, to carbohydrate and other complex organic materials through the photosynthetic process and conserves and recycles mineral resources (Fluck and Baird, 1980; Odum and Odum, 1976).

Producing, processing, packaging, and distributing agricultural production from farms to houses needs around 1,900 of oil equivalents/person/year (Pimentel *et al.*, 2007). In the early 1900s, energy sources around the world were mostly agriculturally derived. Also, industrial products were mainly made from plant matter. Furthermore, early transportation fuels came from agriculture. The risk of volatile energy markets has renewed the interest in producing energy from agricultural products or by-products.

2.10 Agriculture as an Energy Producer

The world demand for petroleum and natural gas is increasing relative to world supplies. Fossil fuel energy can be either replaced with new sources of energy, or optimized in an applied manner (Kitani, 1999; Pimentel *et al.*, 2007). It is predicted that even with the use of more efficient technologies and new energy sources, due to population and economic growth and improving quality of life in developing countries, the fossil fuel demand will increase in the coming years. Higher prices for petrol, diesel, and natural gas are making renewable sources of energy more attractive, economically, suggesting agriculture‘s role as an energy producer (Outlaw *et al*., 2005).

Energy consumption and carbon dioxide emissions are increasing at alarming rates (Ramanathan, 2005). Continued carbon dioxide (CO2) emissions are likely to lead to catastrophic problems (Patterson, 1991; Smil, 2008). Energy activities are either contributing factors, or the main causes, of a significant number of environmental concerns. Major energy-related issues include global climate change, acid deposition, and deterioration of urban air quality (Patterson, 1991). Currently, renewable energy sources are more expensive than fossil fuel generation; however, if the environmental impacts and technical limitations are solved, it is possible to use more bioenergy resources in the future (Mallon, 2006; Tester, 2005; Warren, 2007). Since some thirty years ago, in some countries, such as Brazil, biofuels have been blended with fossil fuels. In these countries, cheap agricultural production, especially sugar, helps the use of biofuels in vehicles (Boyle, 2004; Gerin *et al*., 2008; Kitani, 1999 Warren, 2007).

2.11 The Role of Energy in Agricultural Development

Energy is one of the important elements in modern agriculture. Without energy, farming is impossible; especially, as modern agriculture depends totally on energy use and fossil resources. Energy consumption in agriculture has been increasing in response to the limited supply of arable land, increasing population, technological changes, and a desire for higher standards of living (Hatirli *et al*., 2006; Kizilaslan, 2008; Manaloor and Sen, 2009). Between 1900 and 2000, the global cultivated area increased 80-100% and energy harvested on farms grew six fold. However, in the same period, energy consumption increased 85-fold (Smil, 2008). There is a trend in agricultural production called from farm to last consumer where different sorts of energy sources are used for producing, transporting, processing, packaging, and shopping. The proportion of each part of the trend depends on many factors, such as properties of the crops, distance between the farm and market, kind of processing, and shopping system. It is estimated that around 19% of fossil energy consumed in the United States is used in food production (Pimentel and Pimentel, 2008).

Land, labour, energy, seed, and water were the most interdependent factors in the first agricultural societies, established around 3000 BC in Mesopotamia; since then, over the centuries, humans have slowly improved techniques and tools to increase yield and reduce labour intensity. Domesticated animals, such as oxen and horses helped farmers to cultivate more land; however, 10% of farms were devoted to prepare feed for those animals. Until the 19th century, farmers had lived in a subsistence economy.

After the industrial revolution, populations increased and a large proportion of the population migrated from rural areas to industrial cities to find more employment opportunities. To reduce this gap, farming efficiency had been improved since the nineteenth century by introducing larger and more powerful breeds of horses, artificial fertilizers, and farm mechanization (Boyle *et al*., 2003; Pimentel and Pimentel, 2008).

Energy consumption in agriculture has become more intensive as the Green Revolution led to the use of high yielding seeds, fertilizers, and chemicals as well as diesel engines and electricity (Hatirli *et al.,* 2006). The energy requirements for the production of each crop are usually divided into four categories: crop protection, nutrition, cultivations, and culture (Tzilivakis *et al*., 2005). The sections are further sub-divided into:

i. Energy for the manufacture of crop protection chemicals and fertilizers (including packaging and transport to the farm).

ii. Energy required for carrying out field operations. Each operation is assigned a value based on the type and working width of the machine and, in the case of tillage operations, the operating depth and soil type.

iii. Indirect energy (the energy required for the manufacture of machinery and its maintenance), it includes the operating life times and depreciation periods of machines.

Agricultural economists identified energy consumption as an important determinant of agricultural productivity. In contrast to other sectors, the energy use in agriculture has generally received very little attention from scientists in different countries. The main reasons for this little scientific attention are data shortages and lower levels of multi-disciplinary work, which mean researchers, give little attention to marginal subjects in science. However, energy use in agricultural production has been increasing faster than that in many other sectors (Karkacier and Gokalp Goktolga, 2005). It is clear that energy use in modern agriculture has increased; however, the growth rate of production is higher. Thus, the current energy use per unit weight is less than before (Sauerbeck, 2001). It seems that there is a correlation between energy consumption in agriculture and the global rise of urbanization (Smil, 2008).

Furthermore, energy has an important and unique role in economic and social development, especially in developing countries. However, there is a general lack of rural energy development policies that focus on agriculture. This is mainly due to lower levels of government attention given to the agricultural production, especially in developing countries. Another reason might be the follower character of developing countries as more industrialization is reached by the developed countries, less value they place on agricultural production. Besides that, less-educated and less organized rural population in developing countries have not significantly influenced politicians as in the developed countries (Karkacier *et al*., 2006).

2.12 Energy Saving in Agricultural Operations

Most energy demand from arable and horticultural farming is for fuel. Fuel is consumed for agricultural operations, such as tillage, planting, fertilizer distribution, spraying, and harvesting. Recently, many new types of agricultural machinery have been developed to save time and energy consumption in the field; for example, a combination of disk harrows and cultivator sweeps and a combination of chisel plough and zone. Moreover, new farming operational methods, such as strip tills, minimum tillage, and conservation tillage, have been introduced to replace conventional tillage to save time, costs and fuel and to reduce environmental impacts by reducing the number of passes made by tractors on farms (McLaughlin *et al.*, 2008; Smil, 2008).

The tractor is the most important machine in modern agriculture. Most of the fundamental innovations in tractors happened during the early decades of the twentieth century (Smil, 2008). The worldwide number of tractors in use increased from 11 million, in 1961, to 28 million, in 2006 (FAO, 2008). In contrast, in some regions, the older tractors were replaced with fewer, but more powerful, new ones (Smil, 2008; Stout, 1990). There are a considerable variety of tractors available (brand, model, power, and design). Selecting the right tractor and equipment can make a significant difference to farm efficiency. Some studies show fuel consumption can be reduced by as much as 30% when the tractor is driven with maximum efficiency (Centre for Advanced Engineering, 1996; Pellizzi *et al.,* 1988). Several factors should be considered before selecting tractors, such as engine type, transmission system, and tyre type (Stout, 1990).

To achieve optimum fuel consumption, the tractor and equipment should be adjusted for each specific task and good driving practices must be followed. Moreover, several other factors, such as regular maintenance, optimum wheel slip and tyre size, the use of four wheel drive tractors, operating in higher gears at lower engine speeds and correct tyre pressure, can improve tractor efficiency and reduce fuel consumption on farms. In addition, reducing transport distance, creating larger and longer paddocks, selecting appropriate speeds and depths of operations, and choosing the right time for agricultural operations are some key components of efficient tractor operation (Barber, 2004; Centre for Advanced Engineering, 1996; Conforti and Giampietro, 1997; Kitani, 1999).

Mismatches of tractors and equipment are common on farms. In heavy load operations, such as primary and secondary tillage, tractor size can influence fuel consumption per hectare. Usually, farmers have a limited number of tractors on which to load different equipment. Finding the correct load for all of the heavy and light load applications is difficult. To reduce the problem, farmers always use more powerful tractors for heavy load applications, such as tillage, and use lighter tractors for light load applications, such as mowing and drilling. Using larger field equipment can also help with the correct loading. Using contractors for some specific operations, such as spraying and fertilizing is another common way to reduce load problems. Many indirect factors, such as cultural practices, the availability of capital, personal opinions, and the availability of machinery dealers, also influence the size of tractors and agricultural equipment (Barber, 2004; McLaughlin *et al*., 2008).

2.13 Energy Analysis in Agriculture

There are four analytical methods that provide the rational information needed on which to base energy decisions; life-cycle assessment, energy analysis, economic cost-effectiveness, and environmental assessments (Randolph and Masters, 2008). The energy analysis method and the economic cost effectiveness will be used to estimate energy consumption in rice, maize and yam production. The energy analysis method uses engineering methods to estimate, measure, and predict energy consumption and energy efficiency in different fields (Randolph and Masters, 2008).

Crop systems and energy consumed in agricultural production are very complex. They are affected by weather, soil physicochemical factors, management conditions, pests, diseases, weeds, field size, degree of mechanization, oil prices, livestock production, and the interaction of many other factors. Crop models usually include material (carbon, nitrogen, and water) and energy balance. (CIGR, 1999; Liu, 2009; USDA, 2008; Vlek *et al*., 2004). On the other hand, agricultural energy analysis includes the identification, estimation, measurement and analysis of energy use in agricultural systems (Fluck and Baird, 1980). Energy analysis serves different economic, management, and technical purposes (Stout, 1990).

In the first step of energy analysis, the energy inputs and energy outputs should be identified and evaluated (Kitani, 1999). In 1974, the energy evaluation method was suggested by the IFIAS (International Federation of Institutes for Advanced Study) (Fluck, 1992). Since then, several methods have been used to determine and analyse energy consumption in agricultural production. These studies consist of three methods: statistical analysis, input-output analysis, and process analysis (Fluck and Baird, 1980). Concern about the rising reliance of agricultural production systems on fossil energy sources prompted the use of energy analysis techniques to study the level of energy dependence and comparative energy efficiency of agricultural systems (Stout, 1990). In 1994 Odum attempted to understand the principle of general systems theory in relation to environmental systems. He discussed the relationship between energy inputs and outputs in ecological systems using mathematics. He also stated that energy analyses in agriculture have much wider error margins than energy analyses in industry.

It is important to note that the results of energy studies depend on the set of assumptions used, such as defining outputs and inputs, and the energy equivalent of inputs (Conforti and Giampietro, 1997) but it needs to be pointed out that local results may not be representative of other areas (Liu, 2009). There are different methods to estimate energy consumption; consequently, comparison and evaluation of results from past studies are difficult. For example, human labour has been considered as an energy input in some studies, but not in many others (Conforti and Giampietro, 1997; Sartori et al., 2005).

Furthermore, a general international agreement on how to estimate energy input has been difficult to achieve. In addition, a lack of reliable data for each country and region often forces researchers to take values from other countries without makingadjustments for the different circumstances in those countries (Conforti and Giampietro, 1997; Kitani, 1999).

One of the most important problems in energy analysis is the non-homogeneity of different sources (Fluck & Baird, 1980) and the different norms and coefficients that have been used in different studies. For example, the same amount of fertilizer can have a different energetic cost depending on the technical level of the manufacturing industry. Energy contents depends on the distance of transportation, which is variable, but can be taken as an average value for a region (Kitani, 1999), similarly, two different fuels might have the same energy content; while, they have different attributes (Fluck and Baird, 1980).

There are also problems with energy assignment in the case of multiple outputs, when there is more than one output from a system. In this instance, it is difficult to divide the energy inputs from the outputs. For example, it is impossible to separate the energy needed for grain production from that needed for straw (Conforti and Giampietro, 1997; Fluck and Baird, 1980). Because of these problems, it is difficult to compare one set of data with other published assessments of energy consumption in agriculture in different countries. An appropriate comparison would require a preliminary check on: (i) the primary data; (ii) definitions of inputs and outputs; and (iii) conversion factors used in the calculation (Conforti and Giampietro, 1997; Kitani, 1999).

2.14 Energy Sources in Agriculture

In agro-ecosystems, energy input are classified into four groups: direct and indirect, non-renewable and renewable. The direct energy are the energy which are released directly from power sources for crop production while the indirect energy are those which are dissipated during various conversion processes like energy consumed indirectly in manufacturing, storage, distribution and related activities.

The direct energy consists of diesel, human power and electricity, while the indirect energy contains seeds, fertilizers, farmyard manure, chemicals and machinery. Non-renewable energy includes diesel, chemicals, fertilizers and machinery, and renewable energy consists of human labor, water, seeds and farmyard (Mohammadi *et al.,* 2008).

2.14.1 Direct Energy Inputs

The direct energy input is the energy consumption of physical energy resources for physical work during field operations. Direct energy is required to perform many tasks such as land preparation; irrigation, threshing, harvesting and transportation of agricultural inputs and farm products (Singh, 2000).

Field operations consume significant energy in agricultural production, with most of usage being fuel consumption (Bowers, 1992). Physical energy input such as human labor, draft animal and mechanical power sources have been considered as direct energy input.

1. Human Labor

Before the invention of the tractor, hand and draught domestic animals were the only choices for power generation needed for agricultural operations. Introducing new machines reduced human labour requirements in this industry; however, in field activities, human labour still plays a large role (Smil, 2008). Even now, human power is the main source (73%) of energy in agricultural operations in many of the developing countries (Stout, 1990). Human labour is used for almost every task on farms, from driving, repairing machinery, irrigation, spraying, and fertilizer distribution to management. Many labour activities can be replaced with tractors and other machinery in agricultural production.

However, sometimes this change has little or no effect on crop yields. If all agricultural operations are undertaken by human power, at least 1200 hours/hectare are required. This means that each person can manage just one hectare during a growing season (Pimentel & Pimentel, 2008).Human muscle power was inputs for physical work in field operation activities in crops productions. Human energy is analysed through measuring heart rates and recording oxygen consumption (Stout, 1990). The energy output of humans depends on gender, weight, body size, age, activity, and climate (Smil, 1994).

Therefore, there are different estimations of energy output in human labour. The energy output for a male worker was 1.96 MJ/hr and 0.98 MJ/hr for a female worker. (Mani *et al.,* 2007; Singh and Mittal, 1992). Also, power equivalent reported by Singh and Singh, 1992 for human labor was 74.6 W (0.1 hp).

2. Draft Animal

Animal draught power farming makes man the manager of farm operation rather than the source of power as is the case in the hand-hoe system. While man is only capable of supplying 0.07 kW on a continuous basis, a pair of working animals (work bulls) is capable of supplying an equivalence of one-tenth of their body weights working continuously for about 3 to 4 hours. Animals commonly used are oxen, mules, buffalos, horses, etc., but work bulls (oxen) are the most common in Nigeria.

Animal drawn implements are employed predominantly in the northern part of Nigeria where socio-cultural conditions favour their employment. The limited duration of work per day, coupled with feed requirements to maintain them, particularly in the dry season, tend not to make their choice a favorable economic proposition.Power equivalent reported by Singh and Mittal, 1992 for pair of bullock was 74.6 W (0.1 hp).

In Nigeria, the Emcot plough and Emcot ridger are the most prominent tillage equipment (Starkey, 1989). They are well accepted by farmers in northern Nigeria. The range of animal draught powered equipment in use in Nigeria is a measure of their level of adoption. Other equipment include Arara Unibar, Ariana multipurpose tool bar (consisting of plough and ridger units, as well as cultivator tines, groundnut lifter, weeders and harrows). Although introduced into Nigeria in the 1960s from Senegal and Mali, the Ariana multipurpose tool frame was not widely adopted. The Emcot plough is asymmetrical along its line of draught, lifting and turning soil to one side and inverting it. The degree of inversion depends on the cohesion of the soil and the shape of the plough.

Animal draught powered seeders and planters have also been imported from India and elsewhere but are seldomly used. Cultivation tines are for primary and secondary cultivation and for weeding.

3. Fuel

Fossil fuels have continued to increase in importance as an energy input in society since the introduction of steam engines. In recent decades, oil has become by far the most important source of energy in all economic and production sectors (Singh and Mittal, 1992; Tester, 2005). Until the 1890s, the availability of nutrients and the amount of land for growing food for animate prime movers were the major limits to agriculture, and fossil fuel has solved both these problems (Coley, 2008). The fuel energy input in agriculture is not only of interest to researchers and environmental scientists, but also of importance to farmers who want to minimize production costs (Nguyen and Hignett, 1995). Official statistics pay very little attention to fuel consumption in agriculture. First, in many countries, only fuel purchased by farmers at subsidized prices is considered when analysing fuel consumption in Agricultural and animal production. Second, farmers buy petrol and diesel directly from normal service stations, which are classified in the transport sector (Pellizzi, 1992).

According to Siemens and Bowers (1999), "depending on the type of fuel and the amount of time a tractor or machine is used, fuel and lubricant costs will usually represent at least 16% to over 45% of the total machine costs". However, due to subsidies, the percentage of fuel and lubrication costs is lower in some countries than others. Minimizing fuel consumption, maximizing the tractive advantage of the traction device, and selecting optimum ground speed are the most important factors for the efficient operation of tractors (Grisso *et al.*, 2004). The proportion of fuel consumed in each operation depends on several factors. For example, in warm and dry climatic areas, more fuel is used for irrigation than in other operations; while, in dry land farming, most energy is consumed for tillage and seeding (Centre for Advanced Engineering, 1996; Safa and Tabatabaeefar, 2002). Fuel consumption in specific operations depends on soil conditions, crop type, ground-speed, and rolling resistance (Smil, 1991). The energy component in fuel comes mainly from the heat of combustion; furthermore, the energy required to drill, transport, and refine the petroleum should be added to this amount (Stout, 1990). Fuel consumption, expressed as litres per hectare (l/ha), is a better measurement of fuel consumption than litres per hour (l/h) as it uses the same basis to compare different inputs and operations (McLaughlin *et al.*, 2008). Specific volumetric fuel consumption (SVFC) is the most common method used to estimate energy efficiency of a tractor using the units of l/kW h. However, sometimes instead of SVFC, specific volumetric fuel efficiency (SVFE), with unit of kW h/l, is used (Grisso *et al.*, 2004).

Diesel fuel is the main source of fuel in agricultural machinery because diesel engines are stronger, have a higher efficiency and longer life than petrol engines (Kitani, 1999). Petrol is used only for light trucks and portable sprayers. There are several methods to estimate the fuel consumption of tractors based on the power of tractors; nevertheless, due to the influence of several factors, such as height above sea level, soil conditions (soil type, moisture, density, and residue cover), air pressure, humidity and temperature on tractor power and fuel consumption, most of these methods work only in specific areas (Bertocco *et al.*, 2008; McLaughlin *et al.*, 2002; Serrano *et al.*, 2007). Furthermore, these methods are useful to predict fuel consumption of diesel engines under full load, but under partial loads and conditions when engine speeds are reduced from full throttle, they usually do not work (Siemens and Bowers, 1999).

4. Mechanical Power Sources

The number of tractors and other machinery in agriculture have increased during the last century and the number of tractors worldwide has risen from 11 million in 1961, to 28 million, in 2006 (FAO, 2008). Most commercial energy in agriculture is used in agricultural machinery manufacture and operation (Stout, 1990). This energy can be categorized into energy required for manufacturing, maintenance, and repair (Fluck and Baird, 1980). In some studies, such as Barber (2004) and Wells (2001), it has been calculated as capital energy. Estimating the energy cost of field machinery is much more complicated than determining energy consumption of other agricultural inputs (Smil, 2008). In the agricultural processes, farmers use different agricultural machinery. The determination of the energy consumption in the production of agricultural machinery is very complex, because different companies use different processes for machinery production; also, farmers use machines in different ways. Furthermore, when the farmers cultivate different agricultural products on their farms, it is very difficult to separate the proportion of energy consumption of machinery for a specific agricultural production.

Energy consumed during farm operations is affected by many factors, including weather, soil type, depth of tillage, etc. Therefore, information on fuel consumption and working hours of mechanical power sources for different farm operation will be for calculation of mechanical energy inputs.

Energy required for producing and repairing different agricultural machinery, as estimated by Kitani (1999), is shown in Table 2. Kitani (1999) considered several steps in calculating these energy coefficients: first, the energy required for producing the raw materials; second, the energy used in the manufacturing process; third, and the energy consumption for transporting the machine to the consumer and so forth, and the energy used in repairs and maintenance (Kitani, 1999).

Table 2: Energy Coefficients for Producing and Repairing Different Types of Agricultural Machinery

Equipments	**Energy MJ/kg**
Tractor	138
Mouldboard Plough	180
Chisel Plough	149
Heavy-duty Disc and Field Cultivator	149
Spring tine Harrow	149
Rotary Cultivator	148
Combined Tillage	180
Air Seeder and Grain Drill	133
Fertilizer Spreader	129
Boom-type Sprayer	129
Harvester	116

Sources: Kitani, 1999

2.14.2 Indirect Energy Inputs

Indirect energy is energy used to produce equipment and other goods and services that are used in farm (Pimentel, 1992). Physical energy input in terms of energy sequester of mechanical power source, chemical and biological energy inputs will be considered as indirect energy input. Chemical fertilizer, pesticides were considered as chemical energy input while seed and hormone were considered as biological energy input.

1. Fertilizer

Three different kinds of fertilizer are used in agriculture: chemical (mineral), organic, and biological. Chemical fertilizers have increased the yield more than other innovations in agriculture (Smil, 1991, 2008). Traditionally, soil fertility was maintained and improved by adding livestock manure, planting legumes, and leaving plant residues on the soil (CIGR, 1999). Intensive high-yield agriculture is dependent on addition of fertilizers, especially industrially produced NH_4 and NO_3. In some regions of the world, crop production is still constrained by too little application of fertilizers. Without the use of synthetic fertilizers, world food production could not have increased at the rate it did and more natural ecosystems would have been converted to agriculture. Between 1960 and 1995, global use of nitrogen fertilizer increased sevenfold, and phosphorus use increased 3.5-fold both are expected to increase another threefold by 2050 unless there is a substantial increase in fertilizer efficiency. Fertilizer use and legume crops have almost doubled total annual nitrogen inputs to global terrestrial ecosystems. Similarly, phosphorus fertilizers have contributed to a doubling of annual terrestrial phosphorus mobilization globally.

The use of mineral fertilizers is the fastest growing form of energy consumption in agricultural production (CIGR, 1999; Smil, 2008; Stout, 1990). The global use of agricultural fertilizer increased from 30.5 million tonnes, in 1961, to 102 million tonnes, in 2002 (FAO, 2008).Without using chemical fertilizers, more land needed to be converted from forest and grassland to arable farms. Land use changes may produce more greenhouse gas (GHG) emissions than fertilizer use (Vlek *et al.*, 2004).

There are 16 important elements necessary for the normal growth of plants (Stout, 1990). Plants absorb directly most of these elements from the soil and air. The level of these elements available in soil are based on: the type, amount, and frequency of fertilizer applications, crop and animal production, nutrient contents in products (Nguyen *et al.*, 1995).

Further increases in nitrogen and phosphorus application are unlikely to be as effective at increasing yields because of diminishing returns. All else being equal, the highest efficiency of nitrogen fertilizer is achieved with the first increments of added nitrogen; efficiency declines at higher levels of addition. Today, only 30–50% of applied nitrogen fertilizerand 45% of phosphorus fertilizer is taken up by crops.

A significant amount of the applied nitrogen and a smaller portion of the applied phosphorus is lost from agricultural fields.(Stout, 1990)

There are environmental concerns that need to be taken into consideration when using fertilizer. Elements such as nitrogen and phosphorus can get washed into our surface waters and cause algae blooms and excess plant growth. In the set of sustainability criteria requires that bioenergy crop production use fertilizer as few as possible as for as reasonable yield is achievable. Nitrogen fertilization can increase emission of gases that have critical roles in tropospheric and stratospheric chemistry and air pollution. Nitrogen oxides (NO_x), emitted from agricultural soils and through combustion, increase tropospheric ozone, a component of smog that impacts human health, agricultural crops and natural ecosystems. As much as 35% of cereal crops worldwide are exposed to damaging levels of ozone. NO_x from agro-ecosystems can be transported atmospherically over long distances and deposited in terrestrial and aquatic ecosystems. This inadvertent fertilization can cause eutrophication, loss of diversity, dominance by weedy species and increased nitrate leaching or NO_x fluxes. Finally, nitrogen inputs to agricultural systems contribute to emissions of the greenhouse gas nitrous oxide. Rice paddy agriculture and livestock production are the most important anthropogenic sources of the greenhouse gas methane.(Stout, 1990).

Solutions to these problems will require significant increases in nutrient-use efficiency, that is, in cereal production per unit of added nitrogen, phosphorus and water. There are a variety of practices and improvements that could each contribute to increased efficiency. For example, nitrogen-fertilizer efficiency of maize in the United States has increased by 36% in the past 21 years as a result of large investments in public sector research and extension education, and investments by farmers in soil testing and improved timing of fertilizer application. The development and preferential planting of crops and crop strains that have higher nutrient-use efficiency are clearly essential. Cover crops or reduced tillage can reduce leaching, volatilization and erosional losses of nutrients and increase nutrient-use efficiency. Closing the nitrogen and phosphorus cycles, such as by appropriately applying livestock and human wastes, increases cereal production per unit of synthetic fertilizer applied.(Pimentel *et al*., 2005).

Reliance on organic nutrient sources is a central feature of organic agriculture, but it is unclear whether the 'slow release' of nutrients from organic compost or green manures can be adequately controlled to match crop demand with nutrient supply to increase nitrogen-use efficiency in intensive cereal production systems, thereby decreasing losses to leaching and volatilization. More research on improving efficiency and minimizing loses from both inorganic and organic nutrient sources is needed to determine costs, benefits and optimal practices.

Leguminous clover crops, manure, and organic amendments from off farm can be an alternative nutrient source that may be used instead of mineral fertilizer in agricultural production (Pimentel, 2009). However, these methods cannot provide enough nutrients for the whole world as much as oil and natural gas. Another way to reduce nitrogen fertilizer is using controlled release nitrogen fertilizers (Pimentel *et al.*, 2005).

Leguminous clover crops can provide 100-200 kg/ha nitrogen on farms. Additionally, these plants can collect around 80% more solar energy than conventional crop production. Using leguminous clover crops in appropriate rotation systems can reduce fertilizer requirements by about 40% with minimum yield reductions (Pimentel, 2009; Pimentel *et al.*, 2007). Also, crop rotations can help control pests on farms. Some studies show that better timing and application management can reduce nitrogen fertilizer inputs without yield reductions (Pimentel *et al.*, 2007).

Nutrient-use efficiency is increased by better matching temporal and spatial nutrient supply with plant demand. Applying fertilizers during periods of greatest crop demand, at or near the plant roots, and in smaller and more frequent applications all have the potential to reduce losses while maintaining or improving yields and quality. Such 'precision agriculture' has typically been used in large-scale intensive farming, but is possible at any scale and under any conditions given the use of appropriate diagnostic tools. Strategies that synchronize nutrient release from organic sources with plant demand are also needed.

Multiple cropping systems using crop rotations or intercropping (two or more crops grown simultaneously) may improve pest control and increase nutrient- and water-use efficiency. Agroforestry, in which trees are included in a cropping system, may improve nutrient availability and efficiency of use and may reduce erosion, provide firewood and store carbon.

Four paths of fertilizer loss include runoff, erosion to rivers, leaching to ground water, and gas emissions (Nemecek *et al.*, 2008). The effect of soil quality on crop yield and energy consumption is well illustrated by soil erosion. On average, the depth of top quality soil is around 18 to 20 cm. Some studies show that the loss of each 2.5 cm of topsoil leads to a yield reduction of 250 kg/ha of corn, 161 kg/ha of wheat and 175 kg/ha of soybeans. Also, erosion is a cause of loss of nutrients, organic matter, and soil biota. These losses may reduce crop production by around 15-30% (Pimentel, 2009; Pimentel and Pimentel, 2008).

2. Pesticide

Pests destroy 37% (insect 13%, plant pathogens 12%, and weeds 12%) of all potential agricultural production every year. When the post-harvest losses are added to the pre-harvest losses, total agricultural production losses due to pests increase to 52% (Pimentel and Pimentel, 2008). In agriculture, there are a wide range of pesticides used for a variety of purposes. Pesticides should control weeds, insects, and fungus without seriously injuring to crops (Smil, 2008). Their responsibilities are prevention, avoidance, monitoring, and suppression of weeds, insects, diseases, and other pests. Pesticide use reduces crop losses; however, several hazards from pesticide use including human and animal poisoning, cancer, other chronic effects, reduced biological diversity, and water pollution, should be a balanced against the benefits from pesticides. Some studies show that through appropriate management, it is possible to reduce pesticide use without reducing crop yields (Pimentel and Pimentel, 2008).

The use of pesticides is increasing rapidly worldwide. It is becoming a major environmental hazard and the main source of pollution in agriculture (Lal, 2004). Due to public concern about the environmental effects of agrichemical use, research has begun to quantify it. New components have been introduced to reduce pesticide losses from runoff and leaching and reduce pesticide residues in crops. Also, some research has been carried out to introduce new natural methods. For example, improving the genetic resistance of crops to pests, encouraging pests, biological enemies, employing crop rotation, combinations with conservation tillage and utilizing natural forages and trees are the most important natural biological pest control mechanisms (CIGR, 1999; Lal, 2004; Pimentel and Pimentel, 2008).

Agrochemicals, such as herbicides, insecticides, fungicides and antibiotics, are also major selective agents. Within about one or two decades of the introduction of each of seven major herbicides, herbicide-resistant weeds were observed. Insects often evolve resistance to insecticides within a decade. Resistant strains of bacterial pathogens appear within 1-3 years of the release of many antibiotics. But the need to breed for new disease resistance and to discover new pesticides can be reduced by crop rotation and the use of spatial or temporal crop diversity. Recently, an important and costly pathogen of rice was controlled in a large region of China by planting alternating rows of two rice varieties. This tactic increased profitability and reduced the use of a potent pesticide. The intermingled planting of crop genotypes that have different disease-resistance profiles called a multiline can also decrease or even effectively eliminate a pathogen.

3. Seed

Agricultural crops can be propagated by seeds, tubers or bulbs. Unfortunately, there is little information about energy requirements for seed production (Kitani, 1999).

Clean and proper seeds are provided in packages from seed producer companies and private Institutes. However, some farmers still use their own seeds. On farms, there is a wide range of machines and methods used for planting seed. Different methods use different amounts of seed.

2.15 Technologies Used in Crop Production in Nigeria

Technology as a term means many things to several people and these depend on the setting or the context. Broadly defined, however, technology implies any practical art which utilizes scientific knowledge. The object is usually to advance and enhance human society and conditions. Technology is used to harness the forces of nature and transform the resources that nature has bestowed on man, into goods and services for better quality life. Such goods and services range from power generation to military weaponry, from food production to food processing storage and packaging, to housing and to every other human needs and activities.

Because of the vast agricultural potentialities of Nigeria, major technological investments would be expected in crops production to advance entrepreneurial abilities of investors in the sector as well as to ensure national self-sufficiency in food and fibre production. Investments would also be required in the main and subsidiary industries that would use agricultural produce as raw material. Investment would similarly be required in commodity trading to help stabilize and guarantee prices for farmers and local processors.

2.15.1 Traditional Technologies

These are the simplest and most basic technology for agricultural mechanization in use to some extent for commercial agriculture in Nigeria. These technologies range from the traditional cutlasses and hoes, to the developed stick and stone tools which are the only means to enhance labour productivity in the pre-historic times. These hand tool technologies use man as a power source; and are inefficient and ineffective. Man is limited to about 0.1hp continuous power output and is therefore, grossly inefficient as a primary source of power. However, in many parts of Nigeria where arable farmers are predominantly peasants, traditional technologies are still important.

As a step further in the traditional technology, animal muscle power is substituted for human power, a process which already started in ancient civilization. A large variety of implements and machines have been developed which use animals as the principal power source. According to Ajav (2000), the current animal traction areas of the country can be classified into four distinct regions, namely:

i. Active Animal Traction Region (AATR)
ii. Semi-Active Animal Traction Region (SAATR)
iii. Introductory Animal Traction Region (IATR)
iv. None Animal Tractor Region (NATR)

The following is the overall view of the animal traction technology in Nigerian Arable farming, (Ajav, 2000)

i. Over 2 million Farmers spread across 19 states of the federation are actively involved in the use of animal traction.
ii. Less than 10% of the 2 million active animal traction farmers exploit the full potentials of animal traction through the use of limited available implements. Most of other farmers are only familiar with the ridging and transport equipment and their operation. Most farmers lack animal drawn equipment like ploughs, harrows, planters, weeders and harvesters.

iii. Animal traction implements/equipment are mostly produced and maintained by local blacksmiths. These blacksmiths are mostly constrained by insufficient patronage, unavailability of raw materials, inadequate workshop facilities and ineffective marketing strategies.

2.15.2 Improved Technologies

It is obvious that to transform Nigeria's largely traditional farming system to modern commercial one, there is the need to inject in the system, substantial engineering and technological inputs that are properly managed in terms of both environment and existing/potential technologies (Asoegwu and Asoegwu, 2007).

For commercial arable farming to succeed, agricultural production, processing and utilization must necessarily move from the present subsistence nature to a commercial one through mechanization which must be environmentally friendly. Efforts are being geared towards the replacement of human operator with mechanical systems including automated ones as human operations are inconsistent and less efficient.

Generally, in an effort to reduce human drudgery, minimize labour costs and enhance overall productivity and efficiency, the national research system have designed, fabricated and tested an array of improved agricultural tools and equipment suitable for use under Nigeria's socio-economic environment and conditions.

Scientists in research institutes have developed improved varieties of different local arable crops like cowpea, soyabean, cassava, plantain, banana, rice, etc using a lot of improved agricultural mechanization technologies.

Table 3: Technologies used in Traditional and Modern commercial Farming

Description	Traditional Farming	Modern Commercial Farming
Land Area	Small (1-5ha)	Large (10-100ha or more)
Tools/Equipment	Simple: fire, hoe, axe, digging, sticks, matchets	Complex: Tractors and implements, threshers, and other better quality and higher output equipment.
Crops	Many species (5-80) landraces, no genetic improvement, wide genetic base	Few Species (1-3) improved narrow genetic base.
Animals	Several species	Usually 1-2 species
Labour	Manual, human energy or animal power	Mechanical, petroleum fuels, electric energy
Soil fertility Maintenance	Follows, ash, organic Manures	Inorganic fertilizers, sometimes manure, soil amendments, e.g. Lime, etc.
Pests and Disease Management	Physical/cultural	Mainly mechanical/chemical (insecticides, fungicides, etc)
Crop management	Manual	Growth regulators for defoliation control of flowering, fruit drop, etc.
Harvesting	Manual or with simple tools	Mechanical –Tractors, plus implements: threshers, combine harvesters
Post- harvest handling and drying	Simple sun-drying or over Fires	Mechanical forced air, artificial drying using petroleum fuels, sometimes refrigeration

Source: Okigbo, 1988

2.16 Alternative Energy Sources

Nigeria's energy sources for agricultural production include the use of human power to operate hand tools, animal power for drawn implements, and carbon fuel for motorized and mechanically-driven post-harvest handling and processing machines, and pumps for irrigation (Table 4).

There are no reliable estimates of the country's total energy use. However, out of the conventional energy sources such as electricity, petroleum, gas, coal, and fuel wood, only fuel wood has any substantial use in rural areas. For example, of the total households in Nigeria only 2 percent have access to power (through either rural electrification or self-generation) in 2009 (NBS, 2009). Those with low incomes have limited access to petroleum, gas, coal and the tools that require their use.

Potential alternative energy sources for the rural agricultural sector are biomass (including fuel wood, sawdust, crop and animal residue/waste and biogas), wind, solar power, and small hydropower. Human power and use of draft animals are the dominant inputs into rural agricultural production and processing activities in Nigeria. Alternative energy sources such as biomass, solar power, and small hydropower could serve to reduce the energy deficit in these communities.

2.16.1 Fuel wood

About 50 percent of Nigeria's total energy consumption for agriculture and other domestic food processing activities is from fuel wood. The current reserve potential of 80 million cubic meters per year is reported to be poorly utilized as shown in Table 5.

2.16.2 Crop residue, biogas, animal and human wastes

Huge volumes of agricultural wastes in the form of livestock manure, corn cobs, cassava peelings, rice husks, groundnut shells, sawdust, bagasse, human excreta and the resultant gas (biogas) can be converted into potential sources of energy that can be plowed back into agricultural production and processing activities. This is achievable with the use of a bio-digester (Tejoyuwonu, 1982). Since 1 kilogram of fresh animal wastes could produce about 0.03 cubic meters of gas, Nigeria can produce about 6.8 million cubic meters of biogas daily as shown in Table 5 (Okafor and Joe-Uzuegbu, 2010). Presently, biogas is not widely used in Nigeria's rural economy due to poor knowledge of its energy potential as well as limited resources to purchase the required equipment for its conversion.

2.16.3 Wind Power

The use of wind power for rural agricultural production activities is practically adaptable for residents located along coastlines and in dry regions of Nigeria. This is useful in reducing the human energy involved in activities such as winnowing in rice mills. Since wind is not available in a sustained manner, it limits its usage for many farm activities in Nigeria.

Table 4: Energy sources used for agriculture in rural areas

	Rate of coverage of agricultural activities in Nigeria using energy sources (hour/ha)		
Activities	**Human**	**Animal**	**Carbon-based**
Plowing	-	17 - 25	1.7-2.5
Harrowing	-	8 - 7	0.8-1.5
Ridging	80-250	6-8	1.0 1.4
Fertilizer Application	2-70	_	0.4-1.0
Spraying	2-3	_	0.4-0.5
Planting	100-500	6-8	1-1.5
Weeding	40-150	4-8	0.8-1.2

Source: Ozoemena and Onwualu, 2008

Table 5: Potential sources of energy for rural based agricultural production and processing activities

Source of energy	Potential/Reserves	Energy capacity
Fuel wood	80 million m^3/year	6.0 X 10^9 MJ
Saw dust	1.8 million tons/year	31,433,000 MJ
Crop residue	83 million tons/year	5.3 X 10^{11} MJ
Animal waste	227,500 tons daily	2.2 X 10^9 MJ
Biogas	6.8 million m3 daily	2.7m^3 produces 79.11 MJ
Wind	2-4 m/s at 10m height	5MW
Solar	6.25 hours daily	6.25-7.0 KWh/m^2 per day
Small hydropower	0.143 billion tons	734.2MW

Source: Sambo, 2005

2.16.4 Solar Energy

Nigeria receives an optimal supply of solar radiation (5.5 kilowatt hours per square meter unit). However, only about 0.005% of this amount, is actually converted into energy. The energy challenge mentioned above could substantially be met by solar if 1 percent of the available solar energy can be tapped (FEC, 1984). Solar power has been successfully used in controlled drying of agricultural products, domestic cooking, and pumping water for irrigation in rural areas of China, India, Finland, Kenya, and Bangladesh among others. The limiting factor in rural Nigeria is the lack of technology and funding.

2.16.5 Small Hydropower

Small rivers and streams exist within rural areas in Nigeria, most of which maintain a minimum flow all year round. These streams and rivers can be used to develop hydroelectric energy for rural agriculture (ICEED, 2002). Studies (Aliyu and Eleagbam, 1990) further confirm the great potential of small hydropower to improve on the energy deficits experienced in rural households in Nigeria.

2.17 Energy input-output analysis in crop production

Some studies on energy use and evaluation methods elsewhere were reported. Bridges and Smith (1979) developed a method for determining the total energy input for agricultural practices. The categories of energy considered were those of manufacture, transport and repairs (MTR), fuel and labour. Fluck (1985) also in his study developed two models to quantify energy sequestered in repairs and maintenance of agricultural machinery as compared with the energy input in new machinery. Energy use analysis from the literature have shown that different authors who used different methods for evaluating human energy reported several values of the energy content for manual labour. Hence, there is no universally accepted energy value of manual labour. However, for countries where agriculture is dominated by human energy, it is reasonable to adopt the value obtained by Norman (1978). Sustainable direct energy is required to perform various tasks related to crop production processes such as for land preparation, irrigation, harvest, postharvest processing, transportation of agricultural inputs and outputs. In other word, high level of direct energy such as fuel and electricity are needed to be used at farm for crop production (Alam *et al.,* 2005; Kizilaslan, 2009). Unlike direct energy which is directly consumed at the farm, indirect energy is not directly consumed at the farm rather are the energy used in the manufacture, packaging and transport of fertilizers, seeds, machinery production and pesticides (Ozkan *et al*., 2004). The energy input for the crop production differs to a large extent from area to area and also depending on the level of mechanization. In modern crop production is characterized by the high input of fossil energy (fuel and electricity) which is consumed as direct energy and as indirect energy (fertilizers, pesticides, machinery, etc.). In some low-input farming systems, example in large areas of Africa, the energy input on arable land is lower than 1GJ ha^{-1}, whereas in some modern high-input farming systems in west Europe, it can exceed 30GJ ha^{-1} (Pimentel, 2009; Reed *et al.,* 1986). In the past decade, with increase in energy inputs in agriculture, an equivalent increase in crop yields occurred. Other studies have suggested that the energy use efficiency of our traditional cropping systems have been sharply going downward in recent years due to energy inputs increasing faster than energy output as a result of the growing dependency on inorganic fertilizers and fossil fuels (Hatirli *et al*., 2006; Jekayinfa and Bamgboye, 2007). If the increase in the energy use in the agricultural industry continues, the only chance of producers to increase total output will be using more input as there is no chance to expand the size of arable lands. Under these circumstances, an input-output analysis provides planners and policy-makers an opportunity to evaluate economic interactions of energy use.

2.18 Energy Consumption in Nigeria Agriculture

2.18.1 Energy consumption in millet production

The only available study on energy analysis on millet production in Nigeria is the study by Abubakar and Ahmed (2010) on energy consumption patterns in millet production. (Umar and Ibrahim, 2012). Abubakar and Ahmed (2010) categorised millet farmers into five (5) groups based on the their farm sizes, that is Group I (farmers with farm size greater than or equal to 5 hectares), Group II (farmers with farm size between 3-4 hectares), Group III (farmers with farm size between 2-3 hectares), Group IV (farmers with farm size between 1-2 hectares), Group V (farmers with farm size equal to or less 1 hectare). They reported that energy resources used by the millet farmers were manual (human labour), animal draft, manure, chemical fertilizer, farmyard manure, mechanical and seed (millet) as biological. Group V farmers consumed the highest energy values of 6078 MJ/ha in their millet production while farmers in group I expended the least amount of energy value of 1705 MJ/ha. The variation in energy inputs for farm field operations among the farmers group for millet crop production was said to be depended on cultivation practices and type of machinery used, especially in land preparation, weeding, harvesting, etc.

Total energy output during millet crop production was the highest found in group I farmers and the least total energy output was found in farmers group II with values of 13100 MJ/ha and 2300 MJ/ha respectively. Energy output decreases from group I to group V, this was attributed to decrease in mechanisation level from group I to group V. Energy use ratio values obtained in their study revealed that there was high efficient level of energy use by group III farmers and low efficient energy use by group I farmers with values of 2.4 and 1.3, respectively. High efficient energy use in group III farmers was attributed to use of manual, animal and mechanical energies. While, lowest energy use ratio value for group I farmers was attributed to the manual energy used by the farmers in this group which was laborious and time consuming, a scenario similar to the findings of (Ozkan *et al*., 2004; Alam *et al*., 2005) who conducted similar work for different types of crops in different parts of the world.

2.18. 2 Energy consumption in Rice production

Ibrahim and Ibrahim, (2012) carried out Energy use analysis for rice production in Nasarawa State of Nigeria. The result obtained from their study shows that energy inputs used by the farmers for rice production in the study area were manual (human labour), chemical (fertilizer and diesel), mechanical (machinery), and biological (seed). The average quantity of seed, fertilizer and herbicides used per hectare were not in accordance with the recommended rates of 80 – 100 kg/ha for seed, 300 – 400 kg/ha for fertilizer and 16 – 20 L/ha for herbicide for rice production in Nigeria, (Ekeleme *et al.,* 2008). They found that the total energy input used per hectare for rice production was 12906.8 MJ. Human labour and herbicide contributed the minimum and maximum energy input values of 95.5 MJ/ha and 6913.9 MJ/ha respectively, for rice production, representing 0.7 % and 53.6 %, respectively of the total energy used per hectare. High herbicide used in their study was attributed to excessive usage for weed control in the study area.

The energy efficiency and specific energy for rice production obtained in their study were 4.1 and 3.6 MJ^{-1}, respectively, while energy productivity was 0.3 kg/MJ. However, low productivity in their study was attributed to the usage of local rice varieties in the study area. Non-renewable and renewable energy forms contributed 80.6 and 19.4%, respectively. On the other hand, 84.7 % of the total energy was also in the form of indirect energy, with the direct energy forms contributing 15.3 % of the total energy. Rice production in the study area was observed to be mainly dependent on non-renewable and indirect energy input especially herbicide. They recommends the introduction of integrated weed management system to reduce the excessive use of herbicide for weed control and adoption of high yielding rice varieties such as the Nerica varieties in the study area in order to improve the energy productivity in rice production in Nigeria.

2.18.3 Energy consumption in sesame production

Umar and Ibrahim, 2012 conducted a research on energy use and gross margin analysis for sesame (*Sesamum indicum*) production using organic and inorganic fertilisers in North-central of Nigeria. Human, manure and sesame seed were sources of renewable energy, while machinery, pesticides, NPK and diesel oil constituted non-renewable sources of energy used in production of sesame in the study area. The total energy input expended in the production of sesame using organic and inorganic fertilisers were 2377 and 2960 MJ ha^{-1}, respectively.

Diesel and labour energy inputs dominated the total energy inputs for the two systems. The energy outputs obtained were 13900 and 15000 MJ, respectively. Sesame production using organic fertiliser consumed 71% of direct energy, against 58% for inorganic fertilised sesame farms. Renewable energy input utilisation was higher (50%) in organic than in inorganic fertilised farms (24%). Energy efficiency and productivity was higher in organic than inorganic sesame farms by 14 and 13%, respectively. They concluded that since organic farms were more energy efficient and productive, and returns on investment was equal, sesame production using organic fertiliser should be encouraged across Nasarawa State in Nigeria, for environmental and income sustainability.

2.18.4 Energy consumption in Sweet Orange Production

On Farm Energy Analysis of Sweet Orange Production in Nigeria was conducted by Jekayinfa *et al.,* 2014. The average total energy consumption for sweet orange production obtained in their study was 46.64 GJha^{-1}. About 35% was generated by human labour, 38% from diesel oil and machinery, while other energy resources contributed the remaining 29%. The total energy input was classified as direct energy (86.72%), indirect energy (12.88%) and renewable energy (37.20%) and non- renewable energy (46.52%). The implication of these results is that the energy use pattern in the investigated citrus research farms was based more on non-renewable and direct energy sources than on the renewable and indirect sources, which in other words, shows the more dependence on fossil-based energy sources like diesel and electricity. It therefore follows that citrus production in Nigeria is very sensitive to possible changes in the price of fossil fuels and their supply availability.

In their study, Energy use efficiency (energy ratio) and average energy productivity of sweet orange production were 1.67 and 0.88. The authors concluded that Sweet Orange Production in Nigeria had fair energy use pattern which could still be improved with reduction in energy inputs from cultural practices and a methodological shift from the use of energy from non-renewable sources to renewable ones.

2.18.5 Energy consumption in maize Production

In 2014 study on embedded energy of on farm losses and energy analysis for maize production in Nigeria, Lawal *et al.,* (2014) found the total energy input and output were respectively quantified as 9502.17 and 33510.58 MJha-1. They classified the input energy as industrial energy (84.38%), biological energy (15.62%), direct energy (31.14%) and indirect energy (68.86%). Energy efficiency, energy productivity, specific energy, net energy and agrochemical energy ratio obtained in their study were 3.53, 0.19 kgMJ^{-1}, 5.28 MJkg^{-1}, 24008.41MJha^{-1} and 60.1% respectively. The total embedded energy in the lost maize for the period of study was 6816.13MJ. The high loss of maize on Nigeria farm was an indicator for increased in embedded energy lost from 214.03 -1995.53MJ. Year 2012 had the highest share of embedded energy loss (29.28%) followed by year 2011(28.46%), while lowest share of (3.14%) was estimated for the year 2000. The energy embedded in wasted maize represents a substantial target for decreasing on farm losses in Nigeria maize production

2.18.6 Energy consumption in pineapple production

The energy use and energy use efficiency in a group of pineapples plantations of a research institute in Nigeria was estimated by Jekayinfa *et al*., (2013). They found out that the total energy expenditure and energy output in pineapple production were 6,117.81 MJ/ha and 21,760 MJ/ha, respectively. The output/input energy ratio was 3.56. The different categories of energy input estimated are: direct energy (51.21%), indirect energy (48.79%), renewable energy (14.08%) and non-renewable energy (85.92%). Mean pineapples yield was about 8,000 kg ha –1. The net energy and energy productivity value obtained in their study were 15,642.69 MJ/ha and 1.13 kg/MJ, respectively. Also, they found the total cost of production of pineapples and benefit-cost ratio to be $4,050/ha and 1.70, respectively. Their estimation of energy from pineapples peelings showed that 1 kg of pineapples peelings can replace between 17.71 and 17.92 MJ for heat generation by combustion of biogas and between 11.72 and 17.53 MJ for replacing electricity generation from the national grid, diesel generating set or gasoline generating set.

2.18.7 Energy consumption in mango production

Jekayinfa *et al*., (2013) investigated the On-farm energetics of mango production in Nigeria. They found the average energy consumption of the plantations to be 15,015.16 MJ ha^{-1}. Out of the total energy, 93% was direct and 7% was indirect. Renewable energy accounted for 21% and energy usage efficiency was found to be 1.3. The total energy input into the production of 1 kg of mango as reported in their study was 0.70 MJ. The dominant contribution to input was energy in the form of diesel used in tractor operation and captive power generation (56%), followed by human labor used for land preparation, cultural practices and harvesting (33%), machinery (5%) and chemicals, mainly herbicides (4%). They found out that the use of energetically available residues of mango could give an average value addition of 57,067 MJ/ha. Energy use efficiency and the energy value addition from mango residues, mango production was found to be economically efficient in their study area.

2.19.8 Energy consumption in cassava production

Bamgboye and Kosemani (2015) conducted a research on energy input in the production of cassava. They reported that energy input in the production of cassava varied from 7388.6 – 10888.66 MJ/ha. The energy varied from one farm to another, and the variation was caused majorly by the different amount of biological energy input, chemical energy input and difference in method of equipment acquisitions. Human labour varied from 90.56 – 421.5 MJ/ha, which was higher than 56.5MJ/ha from machinery, but lower than the input fuel of 239 – 2485.6 MJ/ha. The average total energy input of 8560.03 MJ/ha was required in the production of cassava. This is similar to what was obtained in Thailand from cassava (Chamsing, *et al*., 2006).

The pattern of energy use as reported by the authors were chemical fertilizers 64.00%, 19.50% from diesel oil and machinery, human labour 2.20% and 6.67 % of biological energy (stem). About 77.5% of the total energy inputs used in cassava production in their study was indirect (stem, fertilizers, chemicals, machinery) and 22.5% was direct (human labour, diesel). Mean cassava yield obtained in their study was 9,960.00 kg/ha. Their findings is closer to the national average yield for cassava in Nigeria which varies from 10,000 kg/ha to 15,000 kg/ha (Phillips *et al.,* 2004). The net energy and energy productivity value were estimated to be 46,655.77 MJ/ha and 1.18 MJ/kg respectively. The ratio of energy output to energy input was 7.1.

2.18.9 Energy consumption in melon (*colocynthis citrullus* l.) production

Oladimeji *et al.,* (2016) conducted energy use and economic analysis of melon (*colocynthis citrullus* l.) production technologies in kwara state, Nigeria. They classified melon farmers in two categories based on the level of farming technology. Group 1 consist of farmers who owned or rented machinery such as tractor and adopted modern management practices such as chemical fertilizers, herbicides, hybrid seeds, knapsack sprayers, irrigation equipment and received extension services (semi-mechanised). Group 2 was made up farmers that used mostly crude implements such as hoes and cutlasses hence refers to as non-owners of machinery or imbibed low level of farming technology, seldom receive extension contacts and low level inputs usage (traditional method). They found out that Group 1 (semi-mechanised) had total energy input of 4329.7 MJ per ha while Group 2 (traditional) had only 2687 MJ per ha. To cultivate one hectare of melon (egusi) in their study area, Group 1 system used Total Energy Equivalent (TEE) of 45.5 MJ of labour, 451.4 MJ of machinery, 600 MJ of herbicide, 255 MJ of FYM, 661.4 MJ of nitrogen, 119.3 MJ of phosphate, 67 MJ of potassium, 1221.7 MJ of diesel and 908.4 MJ of seedling materials. On the other hand, Group 2 or traditional system used TEE of 97.8 MJ of labour, 216 MJ of herbicide, 753.3 MJ of FYM, and equal amount of nitrogen, phosphate and potassium used as in semi-mechanised and 772.2 MJ of seedling materials.

In semi-mechanised system, human labour and diesel had minimum and maximum energy inputs of 45.5 MJ and 1221.7 MJ representing 1.1% and 28.2% respectively of total energy used per ha. This was expected as human labour was only used mostly for planting operations such as seed sowing and fertilizer application. On the contrary, diesel had highest energy input due to semi-mechanised nature as the fuel was needed to power the machinery for operations such as ploughing, harrowing and ridging and sometimes tractor is used to convey farm harvest and labourers. The results from Oladimeji *et al.,* (2016) further revealed that labour still constitute the minimum energy (97.8 MJ) and chemical fertilizer, the maximum energy (848 MJ) in traditional system in their study area. Both semi-mechanised and traditional systems used hybrid seed material for planting and this reflected in their yield of melon (egusi) of 179 kg and 90 kg/ha, respectively.

2.19 Energy Consumption in processing different crops in Nigeria.

Bamgboye and Jekayinfa, (2006) conducted a study on energy consumption pattern in palm kernel oil processing operations. In their study, the energy used per unit operation for a typical small, medium and large PKO mills for1000kg of Palm-nut were obtained. The total energy required for processing 1000 kg of palm-nut in a small, medium and large mills were 346.77MJ, 217.30MJ and 176.56MJ. They observed that in all the three categories of mills, thermal energy was mostly used, followed by electrical energy and manual energy. About 44.9% of the total energy in the small mill was due to thermal energy, but this increases to 50.1% in the medium mill and 82.4% in the large mill. However, a decrease in the electrical energy consumed was observed from 45.7% in the small mill to 41.4% and 14.9% in medium and large mill respectively. This was attributed to the epileptic supply of electricity from the national grid in Nigeria, leaving the industries to depend more on fuel energy; which represents the largest portion of the total energy used in all the plants (over 80% of the total energy). The differences in fuel energy intensities were due to the differences in quantity of palm-nut processed, sophistication of equipment used and age of factories (including equipment and other associated gadgets).

In all the three categories of mills studied, manual input was least, from 9.4% in small mill to 4.1% and 2.7% in medium and large mill respectively. They identified cracking and oil expression as the most energy intensive operations in all the three mills. In the small mill, cracking and oil expression accounted for 73.3% of the total input energy, 73.4% in the medium mill and 85.2% in the large mill. 176.56MJ, respectively.

In another study on cashew-nut processing mill in Ibadan, Nigeria, fuel consumption varied from 92GJ to 136GJ, accounting for 74.93% and 89.42% of the total energy consumed respectively. This shows that the mill depended more on fuel energy than the other two sources of energy (electricity and manual) (Jekayinfa and Bamgboye, 2003). The major commercial sources of energy in the factory are electricity, coal, oil and gas. Electricity consumption varied from 5.56MJ/kg to 13.48MJ/kg of processed cashew nut; while fuel energy varied from 14.9MJ/kg to 63.62MJ/kg.

Aderemi, *et al.* (2009) examined the pattern of energy consumption in selected food companies in South-western Nigeria; identified the sources of electrical energy waste and assessed the effectiveness of the strategies for electrical energy savings in the industry. Four sub-sectors of food and drinks industry in the category of Small and Medium Enterprises were examined. They include; beverage, bakery and confectionery, grain mills and storage of cold food products. The study revealed that the pattern of electrical energy consumption in the food companies was mainly from generating set; this was due to either low voltage or epileptic power supply from national grid. Also, the study identified 12 direct sources that lead to electrical energy waste and inefficient energy utilization in the food industry. One of these, among others was the energy loss as a result of worn out or slack / misaligned belts that needed timely replacement or tensioning. Other indirect sources identified include lack of training and retraining of staff, power factor of electrical equipment, and equipment age, among others.

In their study, Noah *et al*., (2012) carried out a comprehensive energy audit of Vitamalt Nigeria Plc, Agbara using portable thermal and electrical instruments with the objective of studying the pattern of energy consumption and identifying the possibilities of saving energy in the plant. A five year (2000-2004) data on energy consumption of Vitamalt Nig. Plc was collected and analysed. The study showed that the Normalized performance indicator (NPI) calculated over the span of five years gave an average of 1.2 GJ/m^2 indicating a fair range in energy performance level classification (1.0 - 1.2) while significant savings and improvement in energy usage is achievable. The authors concluded that maximizing efficiency of existing system, optimizing energy input requirement and significant capital investment in procuring new energy conserving equipment must be made for the energy performance level to fall into a good range classification (less than 0.8).

Olaoye *et al.,* (2014) estimated the energy requirements for processing wheat flour in Nigeria. They analyzed energy accounting data based on an input of 250 tonnes of wheat flour during a double shift of 11 hours per shift in a day for a year. The total energy expenditure for processing 250 tonnes of wheat flour was 25339.469 MJ. The most energy intensive operating unit in the production system was identified as the milling unit with 18295.718MJ of energy followed by packaging with 3645.864MJ accounting for 72.20% (0.073 MJ/kg) and 14.39% (0.015 MJ/kg) of the energy required for production, respectively. They recommend that optimization of the energy consumption of the milling unit, process and/or machine design modifications will be required. The process modifications option will be in the conditioning. If the wheat is properly conditioned, the repetitions in the milling process will be reduced. This will reduce energy consumptions and therefore reduce cost of production.

Ibrahim *et al.*, conducted a study on energy analysis of local rice processing in Benue State, Nigeria. Their study was conducted in Makurdi, Aliade and Otukpo rice mills in Benue state, Nigeria. Three cases were selected for each town, making a total of 9 cases.They found the mean energy required for processing 1000kg of paddy to be 6639.87 MJ. The pattern of energy use in their study shows that wood fuel energy was extensively used (5955.56 MJ) 89.69%, followed by liquid fuel (654.22 MJ) 9.85% while manual energy consumed (30.09 MJ) 0.45%. Finally, 6639.87 MJ was the mean energy input required to process a paddy into rice grain output of 1000 kg. Since wood fuel energy consumed above 80% of the average required energy in a local rice mill, it implies that majority of the work is being done in the parboiling unit by the wood fuel. The indicator gives the energy consumption per unit product. The highest energy intensity of 8.0 MJ/kg was recorded in Otukpo, followed by 7.4 MJ/kg in Makurdi and 7.2 MJ/kg in Aliade The variation was because the system is localized. The average energy per unit product was 6.8 MJ/kg. They concluded that the use of rice husks and incorporation of charcoal as fuel would minimize the amount of charcoal used. Efficient milling machines should be used to reduce the high consumption of liquid fuel. Optimization of the entire process is suggested to make the entire process more energy efficient.

Jekayinfa and Olajide (2007) analysed the energy usage in the production of three selectedcassava-based foods in Nigeria. The study was conducted in 18 cassava processing mills situated in the southwestern part of Nigeria to investigate the energy utilizationpattern in the production of three different cassava products, viz: ‘gari’, cassava flour and cassava starch. Six mills specializing in theproduction of each of the products were randomly selected for investigation. They developed an optimization models to minimize the total energy input into each production line. The results of their study showed that the energy requirements per tonne of fresh cassava tuber for production of gari, starch and flour were 327.17, 357.35 and 345 MJ, respectively. They identified the most energy-intensive operations in each production line and concluded from optimization results that the total minimum energy inputs required for the production of gari, cassava starch and cassava flour per tonne of fresh cassava tuber were 290.53, 305.20 and 315.60 MJ, respectively.

2.20 Interaction Effects between Energy, Environment and Agriculture

Throughout history, humankind has tried to control energy in all its different forms. The link between the growth of fossil energy use and increases in biophysical productivity by modem economies in the last century implies that technical change has not provided any real 'emancipation' of production from the natural resources (Mayumi, 1991). From the 1980s, a new factor began to influence energy policy, namely, the environment. Some scientists even believe that energy sources control environmental systems (Odum, 1994). Extraction, transportation, and use of energy have a wide range of environmental impacts (Randolph and Masters, 2008).

In recent years, there has been increasing public concern over the environment (Coley, 2008). First, acid rain and its effects and then global warming gradually raised the agenda for the environment. Governments began to adopt uni-lateral and multilateral targets to control greenhouse gases and other environmental impacts (Hatirli *et al*., 2006; Tester, 2005). Germany and Japan were the leaders of the first significant activities to control NOx emissions in the 1980s (Smil, 2008). Since the Kyoto Protocol became effective, in February 2005, reducing the consumption of fossil fuels has been a main point of environmental policy in many developed and developing countries. Following the Kyoto Protocol, 160 countries agreed to reduce their emissions of CO2 and five other greenhouse gases.

The energy system plays a central role in the interrelated economic, social, and environmental aims of sustainable human development (Randolph and Masters, 2008). In many societies, reducing economic growth due to environmental harm is unacceptable. There are at least two ways to achieve sustainable growth, technological change and conservation and recycling (Coley, 2008). In other words, there are two basic approaches to reduce environmental impacts in the future; (1) mitigating environmental impacts through technology, planning, and policies, and (2) adapting to climate change by lessening its impacts using technology, planning and anticipating effects, and modifying practices and patterns of development in agriculture (Randolph and Masters, 2008).

It is important to remember that the energy issues have become closely linked to environmental and ecological concerns (Patterson, 2006) as the use of fossil fuels and other chemical components are the main contributors to global warming, ozone formation, human toxicity, acid rain, and air and water pollution (Kitani, 1999; Nemecek *et al.,* 2008). Moreover, pollution linked to them have caused many problems for human health, such as eye irritation, asthma attacks, and chronic respiratory diseases (Smil, 2008). Energy industries also make significant contributions to other forms of pollution, ranging from chronic acid mine drainage to recurrent catastrophic spills of crude oil from tankers (Smil, 2008).

Energy consumption and greenhouse gas (GHG) emissions are increasing at alarming rates (Ramanathan, 2005). If GHG emissions continue to increase at the current rate, it is likely to lead to catastrophic problems (Patterson, 1991; Smil, 2008). For example, the atmospheric concentration of CO2 has increased 31% from 280 ppm, in 1750 to 367 ppm in 1999 (IPCC, 2001). Increased concentrations of CO2 and other GHGs in the atmosphere trap more energy from the sun and are recognised as one of the important causes of global warming. Global warming would have several unpredictable effects on the planet. For this reason, the Kyoto Protocol confirmed that GHGs should be reduced to below 1990 levels by the year 2012.

To maintain population growth, food production should continue to rise; therefore, humans must protect the environment, including land, water, energy, forests, and other biological resources (Pimentel and Pimentel, 2008). Energy consumption in crop production increased in developed countries more than in developing countries as a result of 1) increasing population, 2) migration from rural areas to urban areas, and 3) development of new production techniques (Kitani, 1999). Today, developed countries use 70% of global fossil energy annually and developing countries, with 75% of the world population, consume only 30% of the world‘s fossil energy (Pimentel and Pimentel, 2008). Between 1945 and 1985, global total energy consumption increased 500% and the petroleum and natural gas consumption increased by about 900%, while the world‘s population increased by 200% (Haldenbilen and Ceylan, 2005). Studies show that some environmental impacts, such as sulphur dioxide, surface ozone, smog levels, and especially, O3 concentration, may significantly reduce the yield of several agricultural crops, such as wheat, soybean, and corn (Aunan *et al.*, 2000).

Humans have changed and managed ecosystems by using energy to provide more food (Pimentel and Pimentel, 2008). The main problem of increasing the dependency of food production on fossil energy is related to the fact that the rate of fossil energy consumption is certainly faster than that of its production (Martinez, 1990). This implies that current agricultural techniques are unsustainable in the long term because the present consumption of fossil energy will rapidly reduce the availability of fossil fuels for future generations (Conforti and Giampietro, 1997). It is predicted that atmospheric levels of carbon dioxide in the 21st century will be twice the 19th century levels. As a consequence, the global temperature would increase by 1.5˚ C to 4.5˚ C over the next 100 years (Odum, 1994; Stout and Best, 2001). Additionally, high levels of carbon dioxide can reduce the nutritional quality of major agricultural crops, such as wheat, barley, rice, soybean, and potato. It may reduce protein levels by about 15% (Pimentel and Pimentel, 2008).

Global warming resulting from greenhouse gas emissions from agricultural activities is one of the most important environmental issues. Many people believe that agriculture does not play a key role in environmental impacts. But fertilizers, agricultural residue burning, deforestation for land clearing, and domestic animals account for 80% of dinitrogen oxide flows into the atmosphere, 67% of nitrogen fixation, 65% of methane flow into the atmosphere, and 40% of non-methane hydrocarbon emission into the atmosphere (Boyle *et al.,* 2003). Also, the use of fertilizers and pesticides in agricultural production has created a number of health problems (Pimentel *et al.*, 2005).

The contribution of global agriculture to air pollutions through the consumption of energy is small, accounting for about 5-7% of annual GHG emissions (Dalgaard *et al.*, 2001; Outlaw *et al.*, 2005). The global climate is quite a complex system; therefore, it is extremely difficult to predict what will happen to climatic factors, such as rainfall and wind patterns as a result of global warming and changes in the levels of key greenhouse gases, such as CO2, CH4, and N2O (Stout & Best, 2001). Land use changes from forest and grassland to arable farms are the most important source of carbon release from the soil and dead plants into the atmosphere (Lal, 2004; Vlek *et al.,* 2004). Land use changes cause emissions of around 20% of the global annual CO2 emissions (IPCC, 2001). Also, CO2 emission from burning fossil fuels is another important environmental impact of crop production (IPCC, 2001; Koga *et al.,* 2003).

Due to land limitations and environmental impacts, crop yield increase is the main source of growth in agricultural production. Thus, more agricultural inputs, mainly fertilizer, will be needed. There is a significant correlation between agricultural production, energy use, and CO2 emissions (Snyder *et al*., 2009). It is predicted that increasing global temperatures could lead to melting glaciers and the resulting thermal expansion of sea water may raise sea levels. This could threaten some coastal areas and small islands. However, it may also create new opportunities for agriculture. For example, reducing glaciers made way for new lands to appear in Canada, Siberia, and Greenland.

Some suggestions to mitigate GHG emissions in the agriculture sector are by using better farming techniques, reducing fuel consumption in farming operations, manure management practices, and improved grain production practices to raise the stock of organic carbon in soils and biomass (Vlek *et al*., 2004). Due to the circumstances in agriculture, investigation into the effects of economic changes on farm production in the short term is difficult. Farmer's reactions to price changes are always slower than in other sectors. They cannot easily change their plants and trees after sowing and they cannot convert their farms from dairy to arable use in a short time. Also, while changes in input prices, especially the price of oil, influence farmer's decisions, and the final net benefits also play a key role. Therefore, it should not be expected that price manipulations would lead to a significant reduction in CO2 and other GHGs (Manaloor and Sen, 2009; Manos *et al*., 2007).

Due to the variety of operating conditions and farming methods, estimating the emissions from agricultural operations is not easy. For example, burning fuel in agricultural operations gives off CO2 and NO+; nevertheless, their emission rates very depending on the size, type, and age of the machines and farm conditions. Electricity use in agriculture does not emit any pollution directly. However, its use may cause significant emissions in the transmission and at the power plant. Transportation of farm inputs and agricultural production also cause concern as emitters of air pollutants. The critical part is finding the best balance between domestic production with high energy consumption and overseas production with low energy consumption for production, but high energy use for transportation.

Fuel consumption in agricultural operations has been identified as an important contributor to global warming in most agricultural activities (Meisterling *et al*., 2009).

Some studies show that burning fossil energy is responsible for approximately 30% of greenhouse gas emissions (Dalgaard *et al*., 2001). Also, new research will be required for finding best management practices to minimize N2O and soil C levels in agricultural production. Furthermore, the direct and indirect impacts of agriculture are substantial, including global warming, eutrophication, and biodiversity depletion.

Due to increasing food, feed, and other industrial production, more energy will be required in the future for food production. In every sector of production and service activities, energy conservation and effective uses of energy are necessary. Using renewable energy resources is one of the important solutions to reduce environmental impacts (Kitani, 1999). It seems that research should be focused on carbon, nitrogen, and sulphur more than other elements because these elements are water soluble, airborne, and play an important role in the biosphere (Smil, 2008).

2.21 Energy Input

2.21.1 Energy Input in the Production of Crops

Energy requirements in agriculture are divided into direct and indirect. Direct energy is required to perform various tasks related to crop production processes such as land preparation, irrigation, intercultural operation, threshing, harvesting and transportation of agricultural inputs and farm production (Singh 2000). Indirect energy consists of the energy used in the manufacture, packaging and transport of fertilizers, pesticides and farm machinery (CAEEDAC 2000; Kennedy 2000). The direct energy consists of diesel, human power and electricity, while the indirect energy contains seeds, fertilizers, farmyard manure, chemicals and machinery. To determine the energy input, the amount of energy input will be multiplies by its energy equivalent (Jekayinfa *et al.,* 2014). The energy equivalent of input and outputs of in agricultural production is shown by Table 6.

Table 6: Energy Equivalent of Inputs and Outputs in Agricultural Production

Input (unit)	Energy equivalent (MJ)	References
Human Labour (h)	0.27	Jekayinfa and Bamgboye, 2006
Diesel fuel (L)	56.3	Singh*et al*, 2002
Machinery	62.70	Singh*et al*, 2002
Tractor and self-propelled (kg)	9-10	Kitani 1999
Stationary equipment (kg)	8-10	Kitani 1999
Implement and machinery	6-8	Kitani 1999
Tractor 50 kW (h)	41.4	(Tsatsarelis 1993, Fluck 1985)
Plough (h)	22.8	(Tsatsarelis 1993, Fluck 1985)
Sprayer (h)	23.8	(Tsatsarelis 1993, Fluck 1985)
Wagon (h)	71.3	(Tsatsarelis 1993, Fluck 1985)
Pump (h)	2.4	(Tsatsarelis 1993, Fluck 1985)
Nitrogen (kg)	78.1	Demerirean *et al.*, 2006
Phosphorus (kg)	17.4	Demerirean *et al.*,2006
Potassium (kg)	13.7	Demerirean *et al.*, 2006
Chemicals (kg)	120	Singh and mittal 1992
Paddy: Seed (kg)	14.57	Bala and Hussain,1992
Straw (kg)	12.50	Bala and Hussain,1992
Maize (kg)	14.7	Lorzahdeh *et al*, 2011
Yam (kg)	4.95	Calorielab, 2014

2.22 Modelling

Nature is a complex system that includes many interacting and interdependent systems. Different mathematical tools such as models have been developed to solve biological, ecological, and environmental problems. Models can be used to predict an output, classify data, and understand processes. Modelling plant behaviour, due to genetic, environmental and soil conditions, and several direct and indirect factors, is a complex process (Safa, 2011).

2.22.1 Background of Energy Modelling

2The excessive use of energy in the developed and developing countries has created several environmental, commercial, technical, and, even, social problems, which need to be studied. Analysing numerous amounts of different sorts of information is necessary to reduce the energy consumption and its environmental impacts. For analysing the data, predicting estimates for different conditions, and making better decisions, it is necessary to use powerful tools, such as mathematical representations, known as modelling. Energy modelling is an interesting subject for engineers and scientists who are concerned with energy production and consumption and its environmental impacts (Al-Ghandoor *et al*., 2009; Tester, 2005). In the energy area, a wide range of models have been used, from geological models in research on natural resources, to modelling future energy demand (Tester, 2005). The first simple model was designed by Landsberg (1977) to find the best condition of economical solar energy conversion. Since then, several modelling studies on energy have been completed.

Most studies have focused on marketing and trade of crude oil and natural gas and these include Marchetti (1977), Stern (1977), and Borg (1981). Since the early 1980s, scientists, such as Fawkes (1987), Hsu et al. (1987), and Hammarsten (1987), started research on modelling technical aspects of energy. These studies can be classified into energy supply–demand models, forecasting models, optimization models, energy models based on neural networks, and emission reduction models.

2.23 Production Function

Production function analysis for estimation of efficiency of resource use in crop production systems and determination of the optimal resource allocation for adjustment in resource allocation has been employed in some studies (Iheanacho *et al*., 2000; Rahman and Lawal,2003). Rahman and Lawal,2003reported that there was inefficiency in the use of resources. Hence, adjustments in resource allocation for economic optimum might be required to meet the needed percentage change based on the equality of marginal value products and marginal factor costs of inputs. The production function analysis gives the physical or technical relationship between inputs and output in any production scheme or process (Olayide and Heady, 1982; Olukosi and Ogungbile, 1989). Mathematically, this function is differentiable. Its differentiability enables the calculation of the rate of return. It is assumed that the technical relationship between variable factors of production and output can be represented by a production function, which is mathematically expressed as;

$Y = f(Xi \ldots X_n)$ (1)

Y is the quantity of output and Xi, …X_n are factors of production.

It is presumed that there are n factors, one or all may be varied and any of which may be considered fixed. Since output is measured in physical terms, Y is referred to as total physical product.

2.23.1 The Cobb-Douglas Function

The Cobb-Douglas functional form of production functions is widely used to represent the relationship of an output to inputs. It was proposed by Knut Wicksell (1851 - 1926), and tested against statistical evidence by Charles Cobb and Paul Douglas in 1928.

The Cobb-Douglas function is without doubt the most widely used function in general economics (Heathfield and Wibe, 1987). It owes part of its name to Paul Douglas who used US manufacturing data for the period 1899 - 1922 to infer its properties. His colleague Cobb, a mathematician, suggested the functional form. Although the function was initially based on manufacturing data and two inputs (capital stock and labour), it can be extended to include multiple inputs. It can also be used to model consumption (utility functions).

In the literature, Cobb-Douglas function was used by several authors to examine the relationship between energy inputs and production or yield (Singh *et al.,*2002,Hatirli *et al.* 2005). Cobb-Douglas function yielded better estimates in terms of statistical significance and expected signs of parameters among linear, linear logarithmic and second degree polynomial functions. Cobb–Douglas production function is expressed as:

$Y = f(x)\exp(u)$ (2) (Zeynab *et al* 2012)

Equation (2) can be linearized and expressed in the following form as:

Model: $\ln Y_i = a\sum_{j=1}^{n} a_j \ln(X_{ij}) + e_i \qquad i = 1,2, \ldots \ldots \ldots . n$ (3)

Where *Yi* denotes the yield of the *i*th farmer, *Xij* the vector of inputs used in the production process, *a*isthe constant term, *j* represent coefficients of inputs which are estimated from the model and *ei* is the error term. With assumption that, when the energy input is zero, the crop production is zero, Eq. (3) changed to Eq. (4) as

$\ln Y_i = \sum_{j=1}^{n} \alpha_j \ln(X_{ij}) + e_i \qquad i = 1,2, \ldots \ldots \ldots . n$ (4)

(Zeynab *et al* 2012)

With assumption that yield is a function of inputs energy, Model I can be expanded to Eq. (4) as in Equation 5

$$\ln Y_i = \alpha_1 \ln(X_1) + \alpha_2 \ln(X_2) + \alpha_3 \ln(X_3) + \alpha_4 \ln(X_4) \alpha_5 \ln(X_5) + \alpha_6 \ln(X_6) \ldots \qquad (5)$$

Where *X1* is human labor energy, *X2* diesel fuel, *X3* machinery, *X4* seed energy, *X5* Nitrogen fertilizer, *X6* phosphorus fertilizer, *X7* Potassium fertilizer and *X8* Chemical (herbicide) is energy inputs.

Cobb–Douglas function can be used to evaluate the impact of direct, indirect, renewable and non–renewable energy as following forms (Mobtaker *et al.*,2010):

Model 2: $\ln Y_i = \beta_o + \beta_1 \ln DE + \ln \beta_2 \ln IDI + e_i$ (6)

Model 3: $\ln Y_i = \gamma_o + \gamma_1 \ln RE + \ln \gamma_2 \ln IDI + e_i$ (7)

Where *Yi* is the *i*th farmer's yield, *βi* and *γ*i are coefficient of exogenous variables. DE and IDE are direct and indirect energies, respectively, RE is renewable energy and NRE is non–renewable energy.

The marginal physical productivity (MPP) technique, based on the response coefficients of the inputs, can used to determine the sensitivity of a particular energy input to production. The MPP of a factor indicates the change in the total output as a result of per unit change in that input factor in question, keeping all other factor constant at their geometric mean level (Manes and Singh, 2005). In other words MPP is the extra output generated by an extra input. It is not necessary to increase the quantity of a factor of production exactly by 1 unit to find out marginal physical product. We can find out the increase in production corresponding to any small increase in the quantity of factor of production. MPP is found by dividing the change in total physical product by the change in the variable input as follows:

$$MPP_{xj} = \frac{GM(P)}{GM\,(E_j)} \alpha_j = \frac{GM(Y)}{GM\,(X_j)} \times \alpha_j \qquad (8)$$

Where MPP_{xj} is marginal physical productivity of *j*th input, $\alpha_j$is regression coefficient of *j*th input, *G(P)* is geometric mean of production,$GM\ (E_j)$is geometric mean of *j*th input on farm ($E_{ji} = X_{ij}A_i$), *GM(Y)* is geometric mean of productivity and *GM(Xj)* geometric mean of *j*th input on per hectare basis.

Finally, the concept and application of return to scale (RTS) would be described. RTS refers to change in output subsequent to a proportional change in all inputs (where all inputs increase by a constant factor). In the Cobb– Douglas production function, it is indicated by the sum of the elasticity which derived in the form of regression coefficients. If the sum of the coefficients is greater than unity($\sum_{j=1}^{n} \alpha_j > 1$),, then it could be concluded that the increasing returns to scale (IRS). That means an increasing in inputs may result in an increasing in output in greater proportion than the input increase. If the function becomes less than unity (($\sum_{j=1}^{n} \alpha_j < 1$),then it is indicated that the decreasing returns to scale (DRS). That means an increasing in inputs may result in an increasing in output in less proportion than the input increase; and if the sum is equal to one ($(\sum_{j=1}^{n} \alpha_j = 1)$,, it shows that the constant returns to scale; this implies despite changing inputs and the output is constant.

The Relation between the energy inputs and yield was estimated using Cobb-Douglas production function for apple orchards by Fadavi *et al.*(2011). Apple yield was assumed to be a function of human labor (x_1), machinery (x_2), chemical fertilizers (x_3), farmyard manure (x_4), chemical biocides (x_5), irrigation (x_6), packaging (x_7), transportation (x_8), refrigerating (x_9) and diesel fuel energies (x_{10}). The established equation was $\ln y_i = 0.053 lnx_1 + 0.61 lnx_2 + 0.11 lnx_3 + 0.59 lnx_4 - 0.29 \ln x_5 + 0.22 lnx_6 + 3.23 lnx_7 + 0.03 lnx_8 + 0.044 lnx_9 - 0.076 lnx_{10}$ ($R^2 = 0.80$). The coefficient of determination (R^2) obtained for the model was 0.80. Packaging energy was found as the most important variable that influences yield. The elasticity for packaging energy is 3.23, implying that a given 1% change in packaging energy will result in 3.23% increase in yield. The second important input was found as machinery with 0.61 elasticity. Other important variables that influence apple yield are farmyard manure and chemical fertilizer with elasticities of 0.59 and 0.107, respectively.Also, the impact of direct and indirect on yield were investigated. The model developed was$\ln y_i = 0.038 lnDE + 2.33 lnIDE$. Indirect energies were all statistically significant at 1%. Elasticity for indirect energies was 3.23, implying that 1% increase in indirect energies would increases the yield by 2.33%.

Afshar *et al.* (2013) estimated an econometric model for pistachio (*Pistacia vera* L.) production in Markazi Region of Iran using Cobb- Douglass function. Pistacia yield was assumed to be a function of human labor (x_1), fertilizers (x_2), chemical (x_3), irrigation (x_4), electricity (x_5), machinery (x_6) and diesel fuel energies (x_7). Thedeveloped model was $\ln y_i = 0.06 lnx_1 + 0.20 lnx_2 + 0.14 lnx_3 + 0.36 lnx_4 + 0.35 \ln x_5 - 0.05 lnx_6 + 1.02 lnx_7$($R^2 = 0.91$).$R^2$(coefficient of determination) was 0.91,implying that around 91% of the variability in the energy inputs was explained by the model. They reported that the impacts of each input, except machinery energy, could be assessed positive on yield of pistachio. The regression results of the model revealed that the contribution of fertilizer and electricity are significant at 1% level. This indicates that an additional use of 1% for each of these inputs would lead to 0.20%, and 0.35% increase in pistachio yield, respectively. The diesel fuel energy contributed significantly to the yield at 5% level. The impact of machinery energy on pistachio yield was not statistically significant. The sum of the regression coefficients of energy inputs was more than unity (2.08). This implied that 1% increase in the total energy inputs would lead in 2.08% increase in the pistachio yield. Thus, there prevailed an increasing return to scale for estimated models. Mohammadi *et al.* (2010) estimated an econometric model for kiwi fruit production in Iran. They reported that the parameters of human labor, machinery, total fertilizer and irrigation water had significant impacts in improving the yield of kiwi fruit.

Rafiee*et al*. (2010) also concluded that for apple production in Iran, the impact of farmyard manure, irrigation water, electrical energy and chemical fertilizer were significant to the productivity at 1% level.

In another study, Mousavi-Avval *et al*., (2012) analyzed the energy efficiency of sunflower producers using parametric approach. In this study the Cobb-Douglas production function was applied to develop an econometric model between inputs and output. The inputs were human labour (x_1), machinery(x_2), diesel fuel (x_3), chemicals (x_4), fertilizers (x_5), water for irrigation (x_6), electricity (x_7) and seed energies (x_8); while, the sunflower yield was the single output. The developed model was $\ln y_i = 0.06 ln x_1 + 0.25 ln x_2 + 0.95 ln x_3 + 0.02 ln x_4 - 0.01 \ln x_5 - 0.01 ln x_6 - 0.02 ln x_7 + 0.04 ln x_8$($R^2$ = 0.91).R^2 (coefficient of determination) was 0.98, implying that around 98% of the variability in the energy inputs was explained by the model.The results revealed that, human labor machinery, diesel fuel, chemicals and seed energy inputs were the most important inputs, significantly contributed to yield. Also, all of the statistically significant inputs showed the positive relationships with output. Moreover, diesel fuel energy input had the highest elasticity on output (0.95). The second and third important energy inputs were machinery and seed with the elasticity values of 0.25 and 0.14, respectively. With respect to the obtained results, increasing 10% in the consumed energy from diesel fuel, machinery and seed energies, would led to 9.5%, 2.5% and 1.4%, increase in sunflower seed yield, respectively. On the other hand, the impacts of electricity, total fertilizer and water for irrigation energies on yield were estimated statistically insignificant and in the cases of total fertilizer and water for irrigation, the coefficients showed the negative relationship with output. The degree of returns to scale for the model was 1.42. The value of return to scale more than unity implies increasing return to scale for sunflower production in the region. These results indicate that 1% increase in all the energy inputs would result by 1.42% increase in the sunflower production.

Mobtaker *et al*. (2010) developed an econometric model for barley production in Hamedan province of Iran. They reported that human labour, total fertilizer, machinery, diesel fuel, electricity and water for irrigation energies were the important inputs, significantly contributed to yield and machinery energy had highest elasticity. Singh *et al*. (2004) found that the use of electricity and fertilizers energy inputs in zone 4 of Punjab was inconsistent with output of wheat production.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 METHODS

Three crops selected for this study are rice, maize, and yam. The types and sources of energy used in the production of the selected crops were assessed and the energy use patterns for the cultivation and processing of the selected crops were identified.

The study area for rice cultivation were four villages in Ekiti and Ondo States of Nigeria. The villages were Ikoro in Ijero Local Government, Igbemo in Irepodun- Ifelodun, Erio in Ekiti West Local Government and Owena in Ifedore Local Government of Ondo state.

The study for maize production was carried out in four villages in Oyo and Ogun States of Nigeria. The villages include Olorunda in Lagelu Local Government, Eruwa and Onifufu in Ibarapa-West Local Government of Oyo state and Kila in Odeda Local Government of Ogun State.

Survey on yam cultivation was carried out in three Local Government Areas of Benue State namely Ukum Local Government Area, Kwande Local Government Area and Katsina –Ala Local Government Area. The climate of the area can be described as the tropical type.

For each crop, nine established farms were purposively selected and categorised as follows:

i. Small Farm: Farms less than 2 hectares
ii. Medium Farm: Farms between 2 and 10 hectares
iii. Large Farm: farm greater than 10 hectares. (NBS, 2009)

Rice processing mills were categorized as small, medium and large mills as follows:

i. Small Mills: Mills with a processing capacity of below 150kg per hour
ii. Medium Mills: Mills with a processing capacity of 150 to 300 kg per hour
iii. Large Mills: Mills with a processing capacity of 300 to 500 kg per hour(Processor survey, 2003)

Energy related data such as human labour (x_1), fuel (x_2), machinery (x_3), biological (x_4), N.P.K fertiliser (x_5, x_6, x_7) and herbicide (x_8)for 2012 and 2013 growing seasonsduring rice, maize and yam production from land preparation to transportation to storage center were obtainedthrough:

i. Field surveys
ii. Direct measurements
iii. Interviews with farmers and
iv. Structured questionnaires.

3.2 Estimating Energy Inputs in Crop Cultivation

3.2.1 Measured Parameters for Estimating Energy Input in Crop Production

To quantify the energy demands of each unit operation, quantitative data on operating conditions was required for each unit operation. The measured parameters for estimating energy input in each unit operation are as shown in Table 7.

Table 7: Measured Parameters for Estimating Energy Input in Crop Production

S/N	Crop	Operation	Equipment and Principle Adopted	Measured Parameter
i.	Rice Maize Yam	Land preparation	Mechanized: Tractor, Disc plough Disc harrow Power tiller Manual	Quantity of fuel consumed, l Time taken for preparing the land, h Number of person involved
ii.	Rice Maize Yam	Planting	Manual Planter	Time taken for planting the land, h Number of person involved. Weight of seed used, kg Quantity of fuel consumed, l
iii.	Rice	Transplanting	Manual	Time taken for planting the land, h Number of person involved.
v.	Rice Maize Yam	Weeding	Mechanized. Tractor 4W, Boom sprayer Manual :Hoe Knapsack sprayer	Time taken for the weeding, h Quantity of the herbicide, l Number of person involved. Quantity of fuel consumed, l
Vi	Yam	Mulching	Manual	Time taken for the weeding, h Number of person involved
vii.	Yam	Staking	Manual	Time taken for the staking, h Number of person involved.
viii.	Rice Maize Yam	Fertilizer Application	Manual	Time taken to applying fertilizer , h Number of person involved. Quantity of fertilizer used, kg
ix.	Rice Maize Yam	Harvesting	Manual	Time taken for harvesting, h Number of person involved
x.	Rice Maize	Threshing	Mechanical: Thresher Manual	Time taken for the threshing Number of person involved.
xi.	Rice	Winnowing	Manual	Time taken to the winnowing, h Number of person involved.
xii.	Rice Maize Yam	Transportation	Mechanical: Tractor Trailer Manual	Amount of fuel used, l Taken for transportation, h.

The energy evaluation methods for each unit operation are as follows:

Land preparation

Land clearing was done manually in all the farms for rice and yam cultivation, while it was done mechanically using standard machines or tractor and implement for maize production. Tillage was done mechanically using tractor and disc plough in all maize farms and power tiller in all farms, while it was done manually in all yam farms. The time spent on the operation, number of people involved and quantity of fuel consumed by the tractor or power tillerwere recorded. The energy required for land clearing was obtained from Equations9a and 9b according to Bamgboye and Jekayinfa (2006.)

$$E_{\mathrm{lp}} = 3.6(0.075\,N\,Ta)\ \text{MJ} \qquad (9a)$$

When land clearing is totally carried out manually.

$$E_{\mathrm{lp}} = 47.8\,D + 3.6(0.075\,N\,Ta)\ \text{MJ} \qquad (9b)$$

When tractor or power tiller is used.

where:

0.075 = Energy input of an average adult male, kW.

Ta =Useful time spent by a male worker per unit operation,

N is the number of persons involved in an operation

47.8 = Calorific value of diesel, MJ/L

D = Amount of diesel consumed per unit operation, L.

3.6 = conversion factor (1 kWh = 3.6MJ)

Planting

Planting of rice and yam was done manually in all the farms, while planting of maize was done manually in small farms and mechanically in medium and large farms. The time and number of people required to perform the operation, the quantity of fuel usedand the weight of seed (kg) planted were used in the computation of the energy input. The energy consumed was determined from Equation 10:

When land clearing is totally carried out manually.

$$E_{\mathrm{p}} = s_{seed}.Q_{eqv.seed} + 3.6(0.075\,N\,Ta)\ \text{MJ} \qquad \text{(10a) (Chamsing } et\ al\text{, 2006)}$$

When tractor or power tiller is used.

$$E_{\mathrm{p}} = S_{seed}.Q_{eqv.seed} + 47.8\,D + 3.6(0.075\,N\,Ta)\ \text{MJ} \qquad \text{(10b) (Bamgboye and Jekayinfa, 2006)}$$

where:

s_{seed} = Amount of seed applied (kg/ha)

Q_{eqv} = Energy equivalent of seed (MJ/Kg).

Transplanting

Transplanting of rice was done manually in all the farms. The time and number of people required to perform the operation were obtained. The energy consumed was determined from the Equation 11:

$E_{\mathrm{Trasp}} = 3.6(0.075\ N\ Ta)$ MJ (11) (Bamgboye and Jekayinfa, 2006)

Mulching

It is essential to mulch the top of the heap to reduce soil temperature in yam cultivation. Capping each sett with grass or leaves was done manually. The time involved in the operation and the number of people involved were obtained from the survey and the value was computed using the Equation 12:

$E_{\mathrm{much}} = 3.6(0.075\ N\ Ta)$ MJ (12) (Bamgboye and Jekayinfa, 2006)

Staking

Stakes are used to support yam vines in order to obtain good yields by exposing maximum leaf area. Good stakes were cut manually from cassia, siamiea or bamboo poles, and are about 2-2.5 m high. The time required and the number of people involved per hectare were obtained through the questionnaire during the survey. The energy consumed was obtained from Equation 13:

$E_{\mathrm{sta}} = 3.6(0.075\ N\ Ta)$ MJ (13) (Bamgboye and Jekayinfa, 2006)

Weeding

Weed control was done manually using hoe and herbicide generally in all the farms. Pre emergence herbicide spraying and post emergence herbicide spraying was done manually in all rice and yam farms. It was done manually in small maize farms and mechanically in medium and large maize farms. The quantity of fuel used, time consumed in the operation, number of people involved and quantity of herbicide used were obtained. Energy equivalents of 120 and 10 MJ/kg were used to calculate energy for granular and liquid herbicide respectively (Singh and Mittal, 1992). The energy consumed was calculated from Equations 64a and 64b:

When the operation is carried out manually.

$E_{\mathrm{weed}} = \{(3.6(0.075\ N\ Ta) + H_{her}.H_{eqv.her}$ MJ (14a) (Chamsing *et al.*, 2006; Bamgboye and Jekayinfa, 2006)

When tractor-mounted boom sprayer is used.

$E_{\mathrm{weed}} = \{(47.8\ D + 3.6(0.075\ N\ Ta) + (H_{her}.H_{eqv.her})\}$ MJ (14b) (Bamgboye and Jekayinfa, 2006; Chamsing *et al*, 2006)

where:

H_{her}= Applied rate (kg or litre/ha) of herbicide l$^{\text{th}}$ for applied time

H_{eqv} = Energy equivalent MJ/kg or litres of herbicide

Fertilizer Application

The fertilizer application was done manually in all farms surveyed. Parameters obtained to determine the manual energy input in fertilizer application were time required to apply the fertilizer, the quantity of the fertilizer applied and the number of people involved. Chemical energy parameters obtained was the quantity of fertilizer (kg) used. The total chemical energy (fertilizer) input was calculated using energy equivalent value of 78.1, 17.4 and 13.7 MJ/kg for N, $P_{2,}O_5$ and K_2O, respectively (Mudahar and Hignett, 1987; Demerirean *et al.*, 2006). The energy input was obtained using Equation 15:

$E_{\text{fert}} = \{(\sum_{n=1}^{n} \frac{\text{N}.N_{eqv}\cdot}{\text{AP}} + \frac{P_2.O_5.P_{eqv}\cdot}{\text{AP}} + \frac{K_2\text{O}.K_{eqv}}{\text{AP}} + 3.6(0.075\ N\ Ta)\}$MJ(15) (Chamsing *et al.*, 2006;Demerirean *et al.*, 2006, Bamgboye and Jekayinfa, 2006)

where:

N_{eqv} = Energy equivalent value of N = 78.1MJ/kg

P_{eqv} = Energy equivalent value of P_2O_5= 17.4MJ/kg

K_{eqv} = Energy equivalent value of K_2O= 13.7MJ/kg

N = Compound fertilizer rate applied × percentage of N ingredient (kg)

P_2O_5 = Compound fertilizer rate applied × percentage of P_2O_5 ingredient (kg)

K_2O = Compound fertilizer rate applied × percentage of K_2O ingredient (kg)

AP = Planted area (ha)

Harvesting

Harvesting was done manually in all the farms. Energy required to harvest was estimated by measuring the time taken to perform the operation and the number of people involved. Energy input in this operation was calculated from Equation 16:

$E_{\text{harv}} = 3.6(0.075\ N\ Ta)$ MJ (16) (Bamgboye and Jekayinfa, 2006)

Threshing

Threshing of rice was done manually in all the farms, while it was done mechanically using thresher in all categories of maize farms.Thetime spent on the operation, number of people involved and the quantity of fuel used when the operation was mechanically done were obtained.The energy input in this operation was obtained from Equation 17:

When the operation is carried out manually

$E_{\text{thresh}} = 3.6(0.075\ N\ Ta)$ MJ (17a) (Bamgboye and Jekayinfa, 2006)

When thresher is used.

$E_{\text{thresh}} = 47.8\,D + 3.6(0.075\,N\,Ta)$ MJ (17b) (Bamgboye and Jekayinfa, 2006)

Transportation

Transportation to storage facilities was done with Tractor and Trailer. The energy input in transportation consist of thermal energy and manual energy. Energy required in transportation was estimated by measuring the time involved in the operation which include time spent on loading and off-loading the crop, number of people involvedand the quantity of fuel used in litres for the operation was obtained. These was done by filling the fuel tank of the tractor to full capacity before the commencement of the operation. The amount of fuel used to refill the tank is the amount of diesel fuel used intransporting the rice to the storage facility.The energy input was obtained from Equation 18:

$E_{\text{tr}} = 47.8\,D + 3.6(0.075\,N\,Ta)$ MJ (18) (Bamgboye and Jekayinfa, 2006; Odigboh, 1997)

3.2.2 Energy Indicator of energy use in Crop Cultivation

Energy Use Efficiency = $\frac{Energy\ Output\ (MJ/ha)}{Energy\ Input\ MJ/ha}$ (19) (Singh *et al*., 1997).

Energy Productivity = $\frac{Crop\ output(kg/ha)}{Energy\ Input\ (MJ/ha}$ (20) (Singh *et al*., 1997)

Net Energy = $Energy\ output(MJ/ha) - Energy\ Input\ (MJ/ha)$ (21) (Singh *et al*., 1997)

Agrochemical Energy ratio (%) = $\frac{input\ energyfrom\ chemical\ input\ MJ/ha}{Total\ Energy\ Input\ (MJ/ha}$ (22) (Mandal *et al.,* 2002)

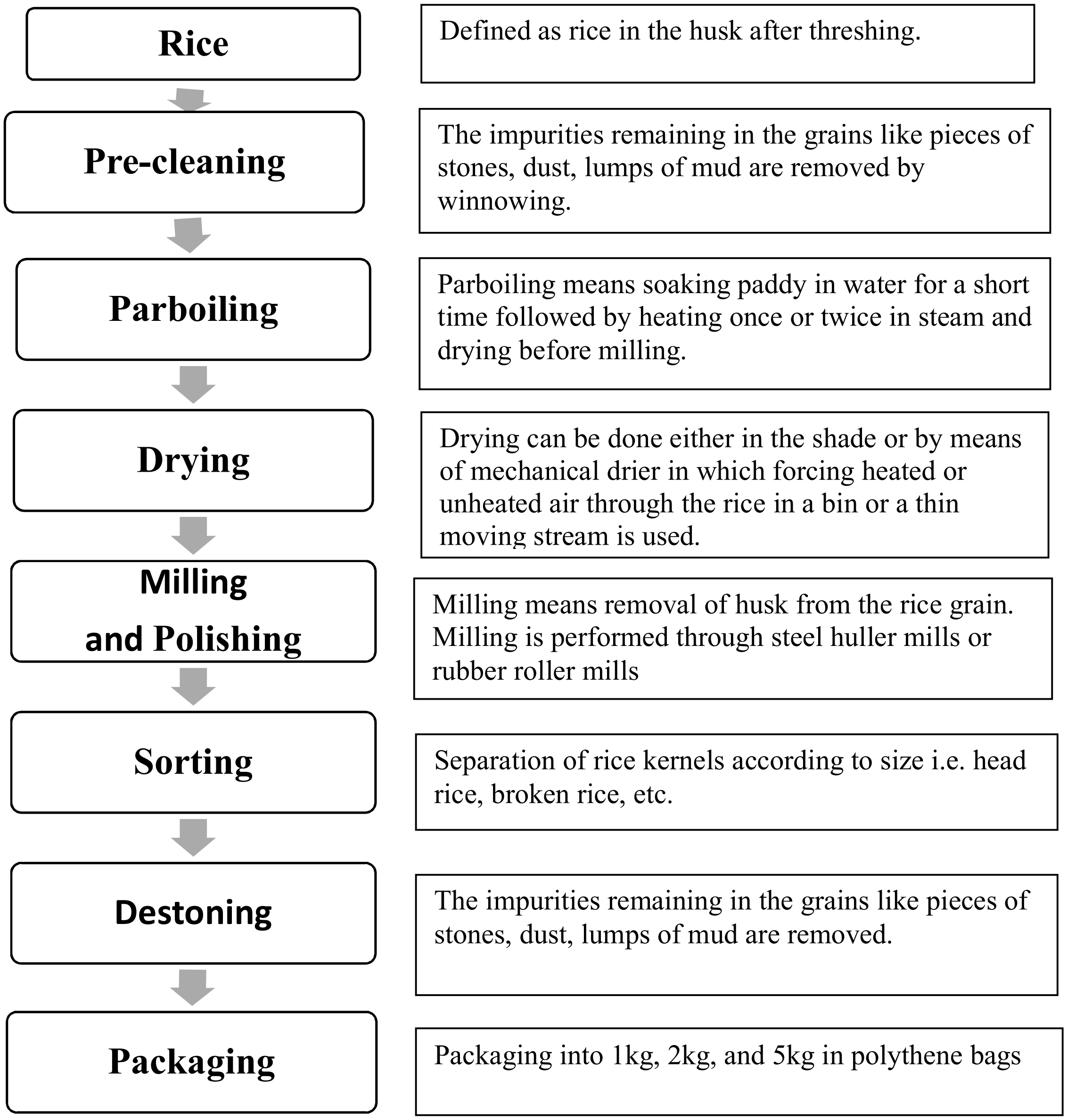
The Energy Output = $yield\ \times energy\ equivalent$ (23) (Singh *et al*., 1997)

3.3Energy Consumption in Different Operations of Rice Processing

Rice processing consists of seven easily defined unit operations (Figure 1). These operations include pre-cleaning, parboiling, drying, milling and polishing, destoning, parboiling and eventually packing. All these process operations require energy in one form or the other as fossil fuel, electricity or human labour.

The data collected from rice miller included power sources (human and prime movers) and agricultural machinery (grain cleaner, parboiler, dryer, and sorter e.t.c). The proforma also included yield of main and by-products. The data was transformed to energy term by multiplying with appropriate energy equivalent factors.

The following methods were adopted in processing of rice:



Rice	Defined as rice in the husk after threshing.
Pre-cleaning	The impurities remaining in the grains like pieces of stones, dust, lumps of mud are removed by winnowing.
Parboiling	Parboiling means soaking paddy in water for a short time followed by heating once or twice in steam and drying before milling.
Drying	Drying can be done either in the shade or by means of mechanical drier in which forcing heated or unheated air through the rice in a bin or a thin moving stream is used.
Milling and Polishing	Milling means removal of husk from the rice grain. Milling is performed through steel huller mills or rubber roller mills
Sorting	Separation of rice kernels according to size i.e. head rice, broken rice, etc.
Destoning	The impurities remaining in the grains like pieces of stones, dust, lumps of mud are removed.
Packaging	Packaging into 1kg, 2kg, and 5kg in polythene bags

Figure 1: Flow Diagram of Rice Processing

The production technologies under study in the three categories of rice mill are as shown in Table 8.

Table 8: Measured Parameters for Evaluating Energy Input in Rice Mill

S/N	Operation	Required parameters
1.	Pre- cleaning	Electrical power, kW
		Time taken for cleaning, h
		Number of persons involved in cleaning
2.	Parboiling	Electrical power, kW
		Fuel consumed, *l*
		Calorific value of fuel used, J/ *l*
		Time taken for parboiling, h
		Number of persons involved in parboiling
3.	Drying	Electrical power, kW
		Time taken for drying, h
		Number of persons involved in drying
4.	Milling	Electrical power, kW
		Fuel consumed, *l*
		Calorific value of fuel used, J/ *l*
		Time taken for milling, h
		Number of persons involved in milling
5.	Sorting	Electrical power, kW
		Time taken for sorting, h
		Number of persons involved in sorting
6.	De-stoning	Electrical power, kW
		Time taken for de-stoning, h
		Number of persons involved in de-stoning
7.	Packaging	Electrical power, kW
		Time taken for packing, h
		Number of persons involved in packing

The type and magnitude of parameters required for the energy evaluation of each unit operation are presented in Table 9:

Table 9: Processing Techniques at the Three Categories of the Rice Mill

S/N	Operation	Equipment and principle adopted		
		Small mill	**Medium mill**	**Large mill**
1.	Pre- cleaning	Manual with the use of tray	Semi-automatic with the use of grain cleaner	Automated with the use of automatic grain cleaner.
2.	Parboiling	Fire wood cooking with the use of drum as the container	Semi-automated Electric boiler	Semi-automated Electric boiler
3.	Drying	Sun drying	A 1-tonne batch-in-bin type dryer. The dryer uses of 5-hp electric motor.	A 1-tonne batch-in-bin type dryer. The dryer uses of 5-hp electric motor.
4.	Milling	Small-capacity single machine, powered by electric motors or diesel engines.	Small-capacity single machine, Powered by electric motors or diesel engines	Small-capacity single machine, Powered by electric motors or diesel engine
5.	Sorting	Manual	Manual	Semi-automated with the use of sorter
6.	De-stoning	Manual	Semi-automated with a de-stoner	Semi-automated with the de-stoner machine
7.	Packaging	Manual	Manual	Semi-automated

Field survey, 2013

The energy evaluation methods for each unit operation are as follows:

Pre- cleaning

Pre-cleaning involves the use of electrical and manual energy. Time taken to perform pre-cleaning operation, the rated horse power of electric motor, hours of operation and the number of operator involved was obtained and recorded. The energy consumed for pre- cleaning was obtained from Equations 24a and 24b:

When totally carried out manually.

$E_{\mathrm{Pc}} = 3.6(0.075\ N\ Ta)$ MJ (24a) (Bamgboye and Jekayinfa, 2006)

When electricity is used

$E_{\mathrm{Pc}} = 3.6(nPt + 0.075\ N\ Ta)$ MJ(24a) (Bamgboye and Jekayinfa, 2006)

where:

n = Efficiency of the electric motor used for particular operation

P = Electrical power consumed for a particular operation, kW

t = Time taken in hours for a particular operation.

Parboiling

Parboiling involved the use of manual and electrical or thermal energy. Time taken to perform the operation, the power rating of the electric heater was obtained when electrical energy was adopted. The weight of log consumed was obtained by measuringwith a weighing scalewhen thermal energy was used. Manual energy was estimated by finding out the number of operators involved and the numbers of hours involved.The energy consumed for parboiling was obtained from Equations 25a and 25b according to Bamgboye and Jekayinfa, (2006)

When electricity is used.

$E_{\mathrm{Pa}} = 3.6(nPt + 0.075\ N\ Ta)$ MJ (25a)

When fire wood is used

$E_{\mathrm{Pa}} = C_{fw}\mathrm{W} + 3.6(0.075\ N\ Ta)$ (25b)

.

where: C_{fw} = (heat capacity of fire wood) 1720 J/kg (Akaaimo and Raji, 2006)

W = Weight of wood. Kg

The weight of wood consumed was obtained from equation 26

$W = \rho\pi d^2 \times {}^{\mathrm{L}}/_{4}$ (26)(Bakari *et al.,* 2010

The density of wood was estimated at 680 kg/m^3 based on the findings of Akaaimo and Raji (2006).

Drying

Drying was done either using natural air or electricity. The time taken to dry 1000kg of rice, the number of people involved in the operation, electrical power consumed by the dryer was obtained and recorded. The energy input in this operation was obtained from Equations 27a and 27b:

When natural air is used.

$E_{\mathrm{dr}} = 3.6(0.075\, N\, Ta)$ MJ (27a)(Bamgboye and Jekayinfa, 2006)

When electricity is used.

$E_{dr} = 3.6(nPt + 0.075\, N\, Ta)$ MJ (27b) (Bamgboye and Jekayinfa, 2006)

Milling

Energy input at this stage includes electrical, thermal and manual energy. The time taken to mill 1000kg of rice, the number of people involved, electrical power rating of the electric motor and quantity of fuel used were obtained.The quantity of fuel used in milling 1000kg of rice was measured by filling the tank to full capacity before the commencement of milling process. After the operation, the quantity of fuel used to refill the tank is the amount of diesel fuel used. The energy consumed was obtained from Equations 28a and 28b (28a) according to Bamgboye and Jekayinfa, (2006).

When electricity is used.

$E_{mill} = 3.6(nPt + 0.075\, N\, Ta)$MJ (28a)

When diesel engine is used.

$E_{mill} = 47.8\, D + 3.6(0.075\, N\, Ta)$ MJ (28b)

Sorting

Sorting was either done manually and mechanically with the use of a sorter. Time taken to sort 1000kg of rice, the number of people involved, the electrical power rating of the sorter were obtained. The energy input in sorting was obtained from Equations 29a and 29b:

When it is done manually

$E_{\mathrm{sort}} = 3.6(0.075\, N\, Ta)$ MJ (29a) (Bamgboye and Jekayinfa, 2006)

When electricity is used.

$E_{sort} = 3.6(nPt + 0.075\, N\, Ta)$MJ (29b) (Bamgboye and Jekayinfa, 2006)

De-stoning

De-stoning is either done manually and mechanically with the use of a de-stoner. Time taken to de-stone 1000kg of rice, power rating of the electric motor, the number of operatorand time involved were obtained. The energy input for de-stoning per ton was obtained from Equations 30a and 30b:

When it is done manually

$E_{\mathrm{de}} = 3.6(0.075\, N\, Ta)$ MJ (30a) (Jekayinfa and Bamgboye, 2006)

When electricity is used.

$\boldsymbol{E_{de} = 3.6(nPt + 0.075\, N\, Ta)}$ MJ (30b) (Jekayinfa and Bamgboye, 2006)

Packaging

Rice is packaged in 1, 5, 10 and 25kg sack or polythene, which must be accurately weighed and labeled. Sealing of polythene was done with electric sealer, while sacks were sowed with needles and thread manually. Time taken to pack 1000kg of rice, the power rating of the electric sealer, the number of operator were obtained. The energy input in packaging was obtained from Equations 31a and 32:

When it is done manually, and

$E_{\mathrm{pack}} = 3.6(0.075\, N\, Ta)$ MJ (31a) (Jekayinfa and Bamgboye, 2006)

When electricity is used.

$\boldsymbol{E_{pack} = 3.6(nPt + 0.075\, N\, Ta)}$ MJ (32) (Jekayinfa and Bamgboye, 2006)

3.3.1 Energy Indicator in processing

Energy Use Efficiency = $\frac{Energy\ Output\ (MJ/ha)}{Energy\ Input\ MJ/ha}$ (33) (Singh *et al.*, 1997).

Energy Productivity = $\frac{Crop\ output(kg/ha)}{Energy\ Input\ (MJ/ha}$ (34) (Singh *et al.*, 1997)

The Energy Output = $yield\ \times energy\ equivalent$ (35) (Singh *et al.*, 1997)

Net Energy = $Energy\ output(MJ/ha) - Energy\ Input\ (MJ/ha)$(36) (Singh *et al.*, 1997)

3.5 Economic Analysis in Crop Production

3.4.1 Economic Analysis in Crop Cultivation

The costs of input energy in the production of rice, maize and yam such as chemicals, fuel, seed, human labour and electricity were obtained. The prices of input were obtained through questionnaire from the farmers to ascertain the actual price of the input. Average prices of 2012 and 2013 growing season were used. The inputs and outputs energies were calculated per hectare, and these input and outputs energies were multiplied by their costs. The cost evaluation methods for each unit operation are as follows:

Land preparation

Amount spent on land clearing and tillage was calculated by finding out the number of people involved in the operation and the cost of labour per person when it was done manually. When it was performed mechanically, the amount of fuel used in land clearing and primarily tillage was obtained from the survey. The cost of each operation was obtained by multiplying the total amount of fuel used in litres by the unit price of fuel and the value obtained was added to the labour cost of the tractor operator.

For yam cultivation, mound/heap making was charged per heap. The cost of making one heap/mound and the average number of heap per hectare were obtained. The cost land clearing and tillage was denoted byC_{lp} andC_{till}, respectively and obtained from Equations 37 and 38, respectively:

When the operation is carried out manually

$$C_{lp} = (N_{lp} \times C_l) \tag{37a}$$

$$C_{till} = (N_{till} \times C_l) \tag{38a}$$

When tractor is used.

$$C_{lp} = \{(Q_f \times P_f) + C_l\} \tag{37b}$$

$$C_{till} = \{(Q_f \times P_f) + C_l\} \tag{38b}$$

where:

$N_p = \text{No of person involed}$

$C_l = \text{ Labour cost (₦)}$

$N_{till} = \text{number of mound/heap per hectare}$

$C_{till} = \text{ Cost of one mound/heap (cost of making one mound was ₦20}$

$Q_f = \text{Amount of fuel used (L)}$

$P_f = \text{Price of fuel per litre. (The unit price of diesel fuel was₦ 160.00 } per\ litre)$

$C_l = \text{Operator labour cost (₦)}$

Planting

Cost input in planting was calculated by addition of labour cost and planting material when it was performed manually. The cost of labour for planting per hectare and number of people involved was used to calculate the labour cost, while the cost of planting materials was calculated by multiplying the quantity of seed or yam sett planted in (kg) by the unit price of seed per kg. Amount spent on mechanical planting wascalculated by the addition of the cost of fuel and machinery, cost of planting materials and operators wage. The planting cost was calculated from Equations 39a and 39b:

When manual labour was used

$$\left\{C_{pl} = (N_p \times C_l) + (P_s \times Q_s)\right\} \tag{39a}$$

When Planter was used

$$\left\{C_{pl} = (N_p \times C_l) + (P_s \times Q_s) + \left(Q_f \times P_f\right)\right\} \tag{39b}$$

where:

N_p = No of person involed

C_l = Labour cost per hectare

P_s = Price of seed per kg. (The cost of rice seed =₦40.00/kg, maize seed =₦50.00/kg and yam sett = ₦12.00/yam sett)

Q_s = Quantity of seed/ sett in kg

P_f = Price of fuel per litre. (The unit price diesel fuel was₦ 160.00 *per litre*)

Q_f = Quantity of fuel in litres

Transplanting

Amount spent on transplanting was calculated by obtaining the cost of labour for transplanting rice per hectare and the number of people involved in the operation. The cost of transplanting was obtained from Equation 40:

$$C_{Transp} = (N_p \times C_l) \tag{40}$$

Mulching

The cost of material used for mulching was not considered in cost estimation since grasses and dry leaves were used. The cost of collecting the mulching materials and human labour cost were used. The number of people involved per hectare and the cost of labour per person were obtained through the questionnaire during survey. The cost of mulching was calculated from Equation 41:

$$C_{\text{stack}} = (N_p \times C_l)\} \tag{41}$$

Staking

The cost of the bamboo used was not considered in staking cost estimation. The cost of collecting the bamboo and labour cost for fixing the bamboo per person was obtained from the survey. Staking was calculated from Equation 42:

$$C_{\text{stak}} = (N_s \times C_s)\} \tag{42}$$

Weeding

Amount spent on weeding operation consists of manual and chemical energy (herbicide) cost. Data on quantity of herbicide,quantity of quantity of fuel, Cost of machinery, number of people involved and cost of labour per hectare was obtained and used in the computation of the cost. Cost of weeding was denoted as C_{w} and calculated from Equations 43a, 43band 43c.

When it is done using hoe

$$C_{\text{w}} = (N_p \times C_l)\} \tag{43a}$$

When Knapsack sprayer is used

$$C_{\text{w}} = \{(N_p \times C_l) + (P_h \times Q_h)\} \tag{43b}$$

When Boom sprayer is used

$$C_{\text{w}} = \{(N_p \times C_l) + (P_h \times Q_h) + (P_f \times Q_f)\} \tag{43c}$$

where:

P_h = Cost of herbicide per litre . (The cost of 1 litre of herbicide was ₦1200.00)

Q_h = quantity of herbicide used in litre

Fertilizer application

The quantity of fertilizer used per bag, number of people involved and labour cost per hectare were obtained from the survey. Equation 44 is used to calculate the cost of applying fertilizer in various farms.

$$C_{\text{fert}} = \{(N_p \times C_l) + (P_{fert} \times Q_{fert})\} \tag{44}$$

where:

P_{fert}=Cost of a bag of fertilizer. (One bag of fertilizer was between ₦5500.00 - ₦6000.00)

Q_{fert} = Amount of bag of fertilizer used

Complete Harvesting

Harvesting was done manually in all the farms. The total cost of harvesting per hectare was obtained by multiplying the number of people involved by the cost of one labour. It is denoted as C_{ch} and calculated from Equation 45:

$$C_{\mathrm{ch}} = (N_p \times C_l) \quad (45)$$

Threshing

The cost of manual threshing was obtained by multiplying labour cost per kg by quantity of threshed crop and cost of mechanical threshing was computed from number of people involved, labour cost for threshing the crop per ton, quantity of fuel in litres used and unit price of fuel.The cost of threshing was denoted C_{thresh} as calculated from the Equations 46a and 46b:

$$C_{\text{thresh}} = (C_{lkg} \times Q_{kg}) \quad (46a)$$

When threshing is done manually

$$C_{\text{thresh}} = (C_l \times Q_{kg} + (Q_f \times P_f)) \quad (46b)$$

When thresher is used.

where:

$C_{lkg} = l$abour cost per kg

Q_{kg} = quantity of threshed crop kg

Q_f = quantity of fuel used in litres

P_f = price of petrol (the unit price of petrol is ₦ 87.00 per litre

Transportation

Transportation cost was obtained from the labour cost of loading the rice on the farm, off loading at the industry and the cost of fuel used in the transportation. This was obtained from Equation 47.

$$C_{tr} = \{(Q_f \times P_f) + C_{ll}\} \quad (47)$$

where:

Q_f = quantity of fuel used (L)

P_f = price of fuel per litre. (The unit price diesel fuel was₦ 160.00 $per\ litre$)

C_{ll} = labour cost of loading and off loading

3.4.2 Cost Analysis in Rice Processing

Pre- cleaning

The cost of labour for pre-cleaning of rice per kg and the number of people involved were obtained from the farmer. The cost incurred in pre-cleaning was calculated from Equations 48a and 48b:

When only manual labour was used

$$C_{pre-cleaning} = (N_{pre} \times C_{pre}) \quad (48a)$$

When auto- loading pre-cleaner was used.

$$C_{\text{pre}-cleaning} = (P_{pre} \times C_{Pre}) + (N_{pre} \times C_{preh}) \quad (48b)$$

where:

N_{Pre} = number of people involved

C_{pre} = $l$abour cost per kg

C_{preh} = labour cost per hour

P_{pre}=Amount of power (kW) used for pre − cleaning

C_P = Unit Cost of power

Parboiling

Parboiling was done by using electricity and thermal energy. The amount of power (kW) and the unit cost of power were obtained when electricity was used. The amount of fire wood used in kg was obtained when thermal energy was used. The cost incurred for parboiling was obtained from Equations 49a and 49b.

When electricity was used.

$$C_{\text{parboiling}} = \{(P_{par} \times C_P) + (C_{par} \times N_{Par})\} \quad (49a)$$

When firewood was used.

$$C_{\text{parboiling}} = \{(Q_{wood} \times P_{wood}) + (C_{par} \times N_{Par}) \quad (49b)$$

where:

P_{par}=Amount of power (kW) used for parboiing

C_P = Unit Cost of power

N_{Par} = number of people involvedin parboling

C_{par} = $l$abour cost of parboiling per kg

$\mathrm{Q_{wood}}$ = Amount of fire wood used (kg)

C_{wood} = Price of fire wood (Price of fire wood was ₦20 per kg)

Drying

Drying of rice was done using manual and electric energy. The amount of electrical power (kW) used in drying and the unit cost of power were obtained. The cost incurred in drying was obtained from Equations50a and 50b:

When electricity was used.

$$C_{\text{drying}} = (P_{dry} \times C_P) + (C_{dry} \times N_{dry}) \quad (50a)$$

When sun-drying was used.

$$C_{\text{drying}} = (C_{dry} \times N_{dry}) \quad (50b)$$

where:

P_{dry}=Amount of power (kW) used for drying

N_{dry} = number of people involved in drying operation

C_{dry} = labour cost of drying per hour

The unit cost of electrical power per kW was ₦15.40

Milling

The cost incurred in milling was calculated by obtaining the amount spent on fuel and labour cost involved. The cost of milling the paddy was calculated from Equations 51a and 51b.

When C. I. engine was used.

$$C_{\text{milling}} = \{(Q_{df} \times P_{df}) + (C_{mill} \times N_{mill}) \tag{51a}$$

When electric motor is used

$$C_{\text{milling}} = (P_p \times C_P) + (C_{mill} \times N_{mill}) \tag{51b}$$

where:

Q_{df} = quantity of diesel fuel in litres

P_{df} = price of diesel fuel in ₦/litre(Price of Diesel fuel is ₦160.0 per litre)

N_{mill} = number of people involved in milling operation

C_{mill} = labour cost of milling operation

P_{mill}=Amount of power (kW) used for milling

Sorting

Sorting was done using manual or electric energy. The amount of electric power (kW) used in sorting and the unit cost of power were obtained when electrical energy was used. The number of people involved in sorting operation and labour cost per person when manual labour was used were obtained. The cost of sorting the paddy was calculated from Equations 52a and 52b:

When manual labour was employed

$$C_{\text{sorting}} = (C_{sort} \times N_{sort}) \tag{52a}$$

When electricity was used.

$$C_{\text{sorting}} = (P_{sort} \times C_P) + (C_{sort} \times N_{sort}) \tag{52b}$$

N_{sort} = number of people involved in sorting operation

C_{sort} = labour cost of sorting operation

P_{sort}=Amount of power (kW) used for sorting

The unit cost of electrical power per kW was ₦15.40

De- stoning

The cost of sorting the paddy was obtained from Equation 53:

$$C_{\text{destoning}} = \{(C_{desto} \times N_{desto}) + (P_{desto} \times C_P)\} \tag{53}$$

where:

$N_{desto} =$ number of people involved in destoning operation

$C_{desto} =$ labour cost of destoning operation

P_{desto}=Amount of power (kW) used for destoning

Packaging

The cost of packaging the processed rice was obtained from Equations 54a and 54b.

When electricity was used, and

$$C_{\text{packing}} = \{(C_{pack} \times N_{Park}) + (P_{pack} \times C_P)\} \tag{54a}$$

When it was sewed manually.

$$C_{\text{packing}} = (C_{pack} \times N_{Pack}) \tag{54b}$$

where:

$N_{pack} =$ number of people involved in packaging operation

$C_{pack} =$ labour cost of packaging operation

P_{pack}=Amount of power (kW) used for packaging

The total cost of processing rice was obtained from Equation 55:

$$C_{\text{T}} = C_{\text{pre-cleaning}} + C_{\text{parboiling}} + C_{\text{drying}} + C_{\text{milling}} + C_{\text{sorting}} + C_{\text{destoning}} + C_{\text{packaging}} \tag{55}$$

3.4.3 Economic Indicators

Gross return, net income and benefit-cost ratio as economic indicators were calculated based on the existing price of the inputs and outputs. The net income was calculated by subtracting the total cost of production per hectare from the gross income of production per hectare. The benefit cost ratio was calculated by dividing the net income of production by the total cost of production per hectare.

Gross return, net income and benefit-cost ratio were calculated using Equations 56 to 58 (Ozkan *et al.*, 2004; Canakci *et al.*, 2005):

Gross return = Grain yield (kg/ ha) × Grain price (₦/kg) (56)

The net income of production = Gross return (₦ /ha) - Total cost of production (₦ /ha) (57)

$$\text{Benefit Cost Ratio} = \frac{\text{The net income of production}}{\text{Total cost of production per hectare}} \tag{58}$$

3.5 Econometric Model estimate of Crop Production

The relationship between the different input and output energy sources were modelled using Cobb-Douglass production function for rice, maize and yam. Crops yield was assumed to be a function of manual, thermal, mechanical, chemical, andbiological energy. In validating these models autocorrelation was performed using Durbin-Watson (DW) test (Hatirli *et al*., 2005).

3.5.1 Cobb-Douglass production function

The relationship between energy inputs and output was investigated using mathematical function relation. In specifying a fit relation, the Cobb-Douglass production function was selected as the best function in terms of statistical significance and expected signs of parameters (Singh *et al*., 2004;Hatirli *et al,* 2006; Mobtaker *et al*. 2010; Mohammadi and Omid *et al*., 2010).

The implicit form of the multiple regression model (production function) is as follows:

$$Y = f\ (x_{1,}x_2, x_3, x_4, x_5, x_6, x_7, x_8\ , e) \qquad (59)$$

Where Y = energy output.

Where x_1 human labor energy, x_2 diesel fuel, $x_3$machinery, $x_4$seed energy, x_5 Nitrogen fertilizer, $x_6$phosphorus fertilizer, x_7Potassium fertilizer and x_8Chemical (herbicide) were energy inputs.

It can be specified in a mathematical form as follows:

$$Y = f(x)\exp(u)$$ (60(Zeynab *et al.,* 2012)

Equation (60) can be linearized and expressed in the following form as:

Model: $\ln Y_i = a \sum_{j=1}^{n} a_j \ln(X_{ij}) + e_i \qquad i = 1,2\,, \ldots n \qquad (61)$

Where *Yi* denotes the yield of the *i*th farmer, *Xij* the vector of inputs used in the production process, *a is* the constant term, *j* represent coefficients of inputs which are estimated from the model and *ei* is the error term. With assumption that when the energy input is zero, the crop production is zero Equation 61 changed to Equation 62 as

$\ln Y_i = \sum_{j=1}^{n} \alpha_j \ln(X_{ij}) + e_i \qquad i = 1,2\,, \ldots n$(62) (Zeynab *et al.,* 2012)

With assumption that yield is a function of inputs energy, Equation 62 was expanded to Equation 63:

$$\ln Y_i = \quad \alpha_1 \ln(X_1) + \ \alpha_2 \ln(X_2) + \ \alpha_3 \ln(X_3) + \ \alpha_4 \ln(X_4)\, \alpha_5 \ln(X_5) \ + \alpha_6 \ln(X_6) \ + \alpha_7 \ln(X_7 + \alpha_8 \ln(X_8))$$ (63) (Zeynab *et al.,* 2012)

Cobb–Douglas function was used to evaluate the impact of direct and indirect energies in a mathematical form as shown in Equation 64:

Model 2: $\ln Y_i = \quad \beta_o + \beta_1 \ln DE + \ln \beta_2 \ln\ IDE + e_i$ (64) (Mobtaker *et al*., 2010)

Where *Yi* is the *i*th farmer's yield, *βi* and *γ*i are coefficient of exogenous variables. DE and IDE are direct and indirect energies, respectively. Equation 64 was estimated using Ordinary Least Square (OLS) technique.

3.5.2 Returns to Scale

Return to Scale (RTS) was determined by adding the elasticity derivedin the form of regression coefficients as shown in equation 65:

Returns to Scale $(RTS) = (\sum_{j=1}^{n} \alpha_j$ (65)(Rafiee *et al.,* 2010)

If RTS is greater than unity (1) $(\sum_{j=1}^{n} \alpha_j > 1)$,, it indicate Increasing Returns to Scale (IRS.

If the function becomes less than unity (1) $(\sum_{j=1}^{n} \alpha_j < 1)$, it Indicated Decreasing Returns to Scale (DRS).

If the sum is equal to one $((\sum_{j=1}^{n} \alpha_j = 1)$,, it indicateconstant returns to scale.

3.5.3 Sensitivity Analysis

The sensitivity analysis of energy inputs on yield was used to identify factors that had a greater effect on the production yield. Marginal Physical Productivity (MPP) method, based on the response coefficients of the inputs was utilized. The MPP of the various inputs was calculated using the $\alpha_j$of the various energy inputs.

MPP was estimated by dividing the change in total physical product by the change in the variable input as follows:

$$MPP_{xj} = \frac{GM(P)}{GM\,(E_j)}\alpha_j = \frac{GM(Y)}{GM\,(X_j)} \times \alpha_j$$ (66) (Singh *et al*., 2004; Rafiee *et al*., 2010)

Where MPP_{xj} is marginal physical productivity of *j*th input, $\alpha_j$is regression coefficient of *j*th input, *G(P)* is geometric mean of production,$GM\ (E_j)$is geometric mean of *j*th input on farm ($E_{ji} = X_{ij}A_i$), *GM(Y)* is geometric mean of productivity and *GM(Xj)* geometric mean of *j*th input on per hectare basis.

3.5.4 Durbin–Watson statistic

In validating these models, autocorrelation was performed using Durbin-Watson (DW) test (Hatirli *et al*., 2005).

$$d = \frac{\sum_{i=2}^{n}(e_i - e_{i-1})^2}{\sum_{i=1}^{n} {e_i}^2} \qquad (67)$$

where:

$e_t = y_i - \hat{y}_i$

y_i and $\hat{y}_i$ are observed and predicted values of the response variable for individual *i*, respectively

n = the number of observations.

To test for positive autocorrelation at significance α, the test statistic d was compared with lower and upper critical values ($d_{\mathrm{L},\alpha}$ and $d_{\mathrm{U},\alpha}$). Upper and lower critical values, have been tabulated for different values of k (the number of the explanatory variables) and n

If $d < d_{\mathrm{L},\alpha}$, there is statistical evidence that the error terms are positively autocorrelated.

If $d > d_{\mathrm{U},\alpha}$, there is no statistical evidence that the error terms are positively auto-correlated.
If $d_{\mathrm{L},\alpha} < d < d_{\mathrm{U},\alpha}$ the test is inconclusive.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Energy input in farm operations for rice production

4.1.1 Energy input in rice cultivation

The results of the energy input in farm operations for rice production are shown in Table 10.It was observed that mode of energy input in all the unit operation were common to all the farms considered irrespective of the farm size of the farm.Energy input in the production of rice varied from 15014.35 to 15256.72 MJ/ha in small farms and it varied from 14624.01 to 15022.5MJ/ha and 14312.64 to 14312.64MJ/ha in medium and large farms, respectively, as shown in Table 10. The variation was caused majorly by the different amount of biological, thermal and chemical energy input.

The average energy inputs per hectare in small, medium and large farm were15107.39, 14842.52 and 14396.62MJ/ha, respectively as shown in Table 11. There was a decrease in the total energy consumption from small farms to large farms. This shows that more energy was needed in small farms than in medium and large farms respectively. This is an indication of better utilization of energy in the medium and large farms, respectively, since there are some measure of mechanisation in medium to large farms. The average energy input obtained from this study was lower than the average energy input of 476003.85 MJ/ha reported by Alipour *et al.* (2012) in Northern Province of Iran. This was because an additional 18487.4 MJ/ha was used for irrigation purpose which was not part of energy use pattern for production of rice in the region surveyed. Rice was grown in swampy area in most of the farm surveyed, which eliminated the need for irrigation. Pimentel and Pimentel (2006) reported that irrigation energy requirement for rice production in United State of America was 8949.6MJ/ha (18% of the total energy requirement) and electrical energy was mainly utilized by electric motor to run irrigation pump. The average energy input in small, medium and large categories of farmsobtained by Iqbal *et al.*(2007) inBangladesh were28373.07, 19085.85 and 17799.61 MJ/ha, respectively, which was higher than what was obtained in this study. High energy input in Bangladesh was attributed to high fertilizer usage and energy input from irrigation. Energy input for rice production in Nasarawa State of Nigeria was 12,906.8 MJ/ha (Ibrahim and Ibrahim, 2012). This is relatively closer to what was obtained in this study.

4.1.2 Energy Input in rice processing

The results of the energy input for processing1000 kg of rice in the mills are shown in Table 12. Energy input in rice processing varied from 416.50 to 545.13 MJ in small mills and it varied from 317.33 to 330.20 MJ and 318.77 to 324.27MJ in medium and large mills, respectively. In small mills, the variation was caused majorly by difference in the mode of operation and level of mechanisation

Table 10: Energy Input and Output in the Production of Rice (MJ/ ha)

Unit Operation	Energy Input (MJ/ ha)								
	Small farms			Medium farms			Large farms		
	Farm 1	Farm 2	Farm 3	Farm 1	Farm 2	Farm 3	Farm 1	Farm 2	Farm 3
Land clearing									
Manual energy	64.14	64.67	64.12	64.30	64.39	64.12	64.67	64.41	64.41
Tillage									
Manual energy	19.36	20.82	21.60	19.42	19.36	19.82	19.60	19.85	19.50
Mechanical energy	698.80	701.00	698.34	637.97	526.56	630.22	478.87	429.30	434.67
Thermal energy	1565.5	1600.34	1607.34	1565	1375.4	1327.5	1255.86	1007.34	1347.00
Planting									
Manual energy	6.21	6.42	6.29	6.64	7.00	6.56	6.59	6.68	6.65
Biological energy	981.65	873.65	993.25	825.70	1019.92	945.25	800.80	919.80	976.55
Transplanting									
Manual energy	43.50	44.90	47.25	43.78	41.92	43.07	40.00	41.70	40.09
Fertilizer application									
Manual energy	19.15	18.96	19.36	19.40	19.16	18.02	18.93	16.27	19.00
Chemical energy N	9684.40	9840.60	9762.50	9762.50	9918.70	9528.20	9684.40	9840.60	9528.20
P_2O_5	511.15	478.50	521.3	521.00	464.6.00	553.30	522.00	421.10	478.50
K_2O	412.15	390.00	426.90	411.000	365.80	421.27	411.00	397.30	397.300
Weeding									
Manual energy	64.40	63.95	64.93	64.47	64.40	63.95	64.93	64.47	64.04
Chemical energy (Herbicide)	288.00	238.40	239.20	248.40	286.80	292.20	243.40	229.20	301.90
Mechanical energy	259.80	257.00	364.25	380.80	257.00	257.00	364.25	364.25	257.00
Harvesting									
Manual energy	59.75	60.57	62.33	60.02	60.52	61.11	59.92	60.22	60.00
Threshing									
Manual energy	25.66	26.02	25.45	25.11	26.02	25.45	25.11	25.24	25.16
Transportation									
Manual energy	23.00	22.30	22.31	21.73	23.49	21.71	21.60	23.12	21.57
Thermal energy	243.00	226.00	227.50	249.00	248.00	249.00	275.56	274.90	272.40
Mechanical energy	81.97	80.25	82.50	96.25	91.97	96.25	102.65	106.89	103.30
Energy Input (MJ) /ha)	15051.1	15014.35	15256.72	15022.5	14881.02	14624.01	14460.15	14312.64	14417.25
Yield (Kg/ha)	6275.00	6550.00	6960.00	7000.00	6860.00	7322.00	7200.00	7450.00	7442.00
Energy Output (MJ/ha)	92,242.50	96,285.00	102,312.00	102,900.00	100,842.00	107,633.00	105,840	109,515.00	109,397.40

Table 11: Average Energy Input and Output in the Production of Rice (MJ/ ha)

	Energy Input (MJ/ ha)		
Unit Operation	**Small farms**	**Medium farms**	**Large farms**
Land clearing			
Manual energy	64.31	64.26	64.49
Tillage energy			
Manual energy	20.59	19.53	19.65
Mechanical energy	699.38	598.25	447.61
Thermal energy	1591.06	1422.63	1203.40
Planting			
Manual energy	6.30	6.73	6.64
Biological energy	949.51	930.29	899.05
Transplanting			
Manual energy	45.21	42.92	40.59
Fertilizer application			
Manual energy	19.15	18.86	18.06
Chemical energy N	9762.5	9736.46	9684.40
P_2O_5	503.65	512.96	473.86
K_2O	409.68	399.35	401.86
Weeding			
Manual energy	64.42	64.27	64.48
Chemical energy (Herbicide)	255.20	275.97	258.16
Mechanical energy	293.68	298.26	328.50
Harvesting			
Manual energy	60.88	60.55	60.04
Threshing			
Manual energy	25.71	25.52	25.17
Transportation			
Manual energy	22.53	22.31	22.096
Thermal energy	232.16	248.66	274.28
Mechanical energy	81.57	94.82	104.28
Energy Input (MJ/ha)	15107.39	14842.52	14396.62
Yield (kg/ha)	6595.00	7060.65	7364.00
Energy Output (MJ/ha)	96946.50	105536.00	108250.80

Table 12: Estimates of energy consumed (MJ) for various rice processing operations.

	Energy Input (MJ)								
Unit Operation	**Small mills**			**Medium mills**			**Large mills**		
Energy Input (MJ)	**Mill 1**	**Mill 2**	**Mill 3**	**Mill 1**	**Mill 2**	**Mill 3**	**Mill 1**	**Mill 2**	**Mill 3**
Pre- cleaning									
Electrical energy	12.93	11.90	12.27	12.93	11.84	11.87	12.60	11.42	11.75
Manual energy	1.16	0.89	1.12	--	--	--	--	---	---
Parboiling									
Electrical energy	--	--	--	53.44	52.46	53.56	52.35	51.88	51.46
Thermal energy	179.3	167.0	185.1	--	--	--	--	--	--
Manual energy	1.27	1.22	1.35	1.26	1.23	1.20	1.20	1.26	1.22
Drying									
Electrical energy	--	--	64.14	58.66	53.23	52.95	53.85	53.66	55.06
Manual energy	17.96	16.20	1.20	1.14	1.21	1.13	1.11	1.305	1.155
Milling									
Thermal energy	214.55	205.06	200.61	181.835	186.38	175.5	181.3	179.25	176.85
Manual energy	0.91	0.85	0.93	0.90	0.85	0.84	0.80	0.87	0.74
Sorting									
Electrical energy	9.4	10.01	9.87	8.74	9.07	9.00	9.72	8.19	9.10
Manual energy	1.36	1.325	1.375	1.365	1.355	1.37	1.37	1.31	1.275
De-stoning									
Electrical energy	---	----	64.16	7.3	7.3	7.11	7.525	7.325	7.4
Manual energy	---	----	1.81	1.50	1.59	1.54	1.28	1.20	1.56
Packaging									
Electrical energy	---	----	0.65	0.64	0.625	0.64	0.645	0.645	0.645
Manual energy	2.15	2.05	0.545	0.535	0.565	0.62	0.52	0.57	0.56
Total energy use	440.99	416.50	545.13	330.2	327.70	317.33	324.27	318.88	318.77
Yield (kg)	612.5	615.0	615.5	635.0	635.0	637.5	640.70	647.5	664.5

Table 13: Average energy consumed (MJ) for various rice processing operations.

	Energy Input (MJ)		
Unit Operation Energy	**Small Mills**	**Medium Mills**	**Large Mills**
Pre- cleaning			
Electrical energy	12.93	12.21	11.92
Manual energy	1.05	-	-
Parboiling			
Electrical energy	-	53.15	51.89
Thermal energy	177.1	-	-
Manual energy	1.28	1.23	1.22
Drying			
Electrical energy		54.94	54.19
Manual energy	17.96	1.16	1.19
Milling			
Thermal energy	214.55	181.23	179.13
Manual energy	0.91	0.86	0.80
Sorting			
Electrical energy	9.45	8.93	9.00
Manual energy	1.36	1.36	1.31
De-stoning			
Electrical energy	7.47	7.23	7.41
Manual energy	1.81	1.54	1.34
Packaging			
Electrical energy	0.65	0.63	0.64
Manual energy	1.58	0.57	0.55
Total energy use (MJ)	447.9	325.04	320.59
Yield (kg)	614.00	621.00	650.00

Drying was done using sun drying method in mills 1 and 2. Solar energywas not considered in the computation of the energy requirement for drying in the two mills.

Also, rice was not de-stoned before it was packaged in mills 1 and 2, thus contributing to the variations observed in the energy consumption in the two mills. In the medium and large mills, it was observed that the modes of operation were similar.

Theaverage total inputenergy for processing 1000 kg of riceinsmall, medium and large millswere442.01,325.04 and 320.59 MJ, respectively, as shown in Table 13.Therewasadecreaseinthetotalenergyconsumption fromsmalltolargemills, indicating that there was better utilizationof energyinmediumandlarge mills.This shows that more energy was needed in the small mills than in the medium and large mills. This is an indication of better utilization of energy in the medium and large scale mills.

4.2 Energy Use Pattern in Rice Production

4.2.3 Energy Use Pattern in Rice Cultivation

Energy resources used by the farmers in all the farms were manual, chemical (fertilizer and herbicide), mechanical, thermal and biological energy (rice seed) as shown in Figure 2.

Chemical energy were 10931.01, 10924.74 and 10818.28 MJ/ha which accounted for 72.35, 73.60 and 75.14% in small, medium and large farms, respectively, as shown in Figure 2. Therewasadecreaseinthechemicalenergyconsumption fromsmallfarmstolargefarms.This trend showed that fertilizer was better utilized in medium and large farms.Inallthefarms, chemical energy wasmostly used,followedbybiologicalenergy in small farms andmechanical energy in medium and large farms.These findings were similar to that of Phipps *et al*. (1976). Also, it corroborated the findings of Khan (2010) that the greatest amount of energy input in rice cultivation is from chemical fertilizer (43%).

The pattern of energy use showed that thermal, mechanical, biological and manual energy were1823.22, 1074.63, 949.51 and 329.10 MJ/ha which accounted for 12.06, 7.11, 6.28, and 2.17%, respectively, in small farms, as shown in Figure 2. Thermal, mechanical, biological energy (seed) and manual energy were 1671.27, 991.33, 930.29 and 324.95 MJ/ha which accounted for 11.26, 6.67, 6.26 and 2.19% of the total energy, respectively, in medium rice farms. In large rice farms, thermal, biological energy (seed), mechanical, and manual were 1277.67, 899.05, 880.39 and 321.19 MJ/ha which accounted for 10.26, 6.24, 6.11 and 2.23 %, respectively. Therewas adecrease inthermal and mechanical energy used per hectare fromsmalltolargefarms, indicating that energy utilised from these resources decreased as mechanisation increased.

The total percentage of mechanical energy input in small (7.11%), medium (6.67) and large farms (6.11) was low.This indicated low mechanization level in rice production in the survey region. Tillage and transportation were the only operations that was mechanized generally in all the farms. Efforts should be made at increasing the level of mechanisation of rice production in Nigeria to be self-sufficient in rice production.

The contributions of direct (manual, thermal) energy in small, medium and large farms were 14.24, 13.44and 12.49 %, respectively. Indirect energy (biological, chemical and mechanical) in small, medium and large farms were 85.75, 86.55 and 87.50%, respectively, as shown in Figure 3. This is similar to the finding of Ibrahim and Ibrahim (2012) which reported that 15.3 % of the total energy in rice production was direct energy and indirect energy contributed 84.7 % of the total energy. Faziollah, (2011), also reported that direct energy for rice production in semi-mechanized andtraditional systems were 10.93 and 11.06% of total energy consumption, while indirect energy were89.07 and 88.94% of total energy consumption.This finding implies that rice production in the study area was mostly dependent on indirect energy especially chemical fertiliser.

Considering theunitoperationsduringproduction(Figures4to7),fertilizer application and tillage wereobservedtorequiremoreenergyinputinall the farms. This is similar to what was obtained in Bangladesh from Boro rice (Igbal, 2007). In case of Boro rice, the greatest amount of energy was consumed infertilizer application followed by irrigation and tillage. Insmall rice farms in this study, fertilizer applicationandtillage accounted for 70.79% (10694.97MJ/ha) and 15.29% (2310.86 MJ/ha) ofthetotalinputenergy, while fertilizer application and tillage accounted for73.4%(10667.63 MJ/ha)and 13.74% (2040.41 MJ/ha)inthe medium farmsand73.47%(10578.18 MJ/ha)and 11.60% (1670.66 MJ/ha)inthelarge farms. Tillage operation becoming the second highest energy consuming operation was because the operation was mechanized in all the farms. High energy input in tillage operation was due to high thermal energy used for the operation.Thevariation in energy used for this operationin all the farms was due to noticeablevariationsinthe thermalrequirementsbythetillage equipment in all the farms.

Planting, weeding and transportation accounted for 6.32, 4.05 and 2.22 % of the total energy input,while, land clearing, harvesting, transplanting and threshing were 2.17, 0.40, 0.29 and 0.17% of the total energy input, respectively, in small farm as shown in Figure 4. Planting, weeding and transportation accounted for 6.31, 4.30, and 2.4%, respectively, while land clearing, harvesting, threshing and transplanting accounted for 0.43, 0.40, 0.17 and 0.28%, respectively, in medium rice farms as shown in Figure 5. Similarly, planting, weeding, transportation accounted for 6.29, 4.46 and 2.74%, respectively, while land clearing, harvesting, threshing and transplanting accounted for 0.44, 0.41, 0.17 and 0.27% ,respectively,in large rice farm as shown in Figure 6.

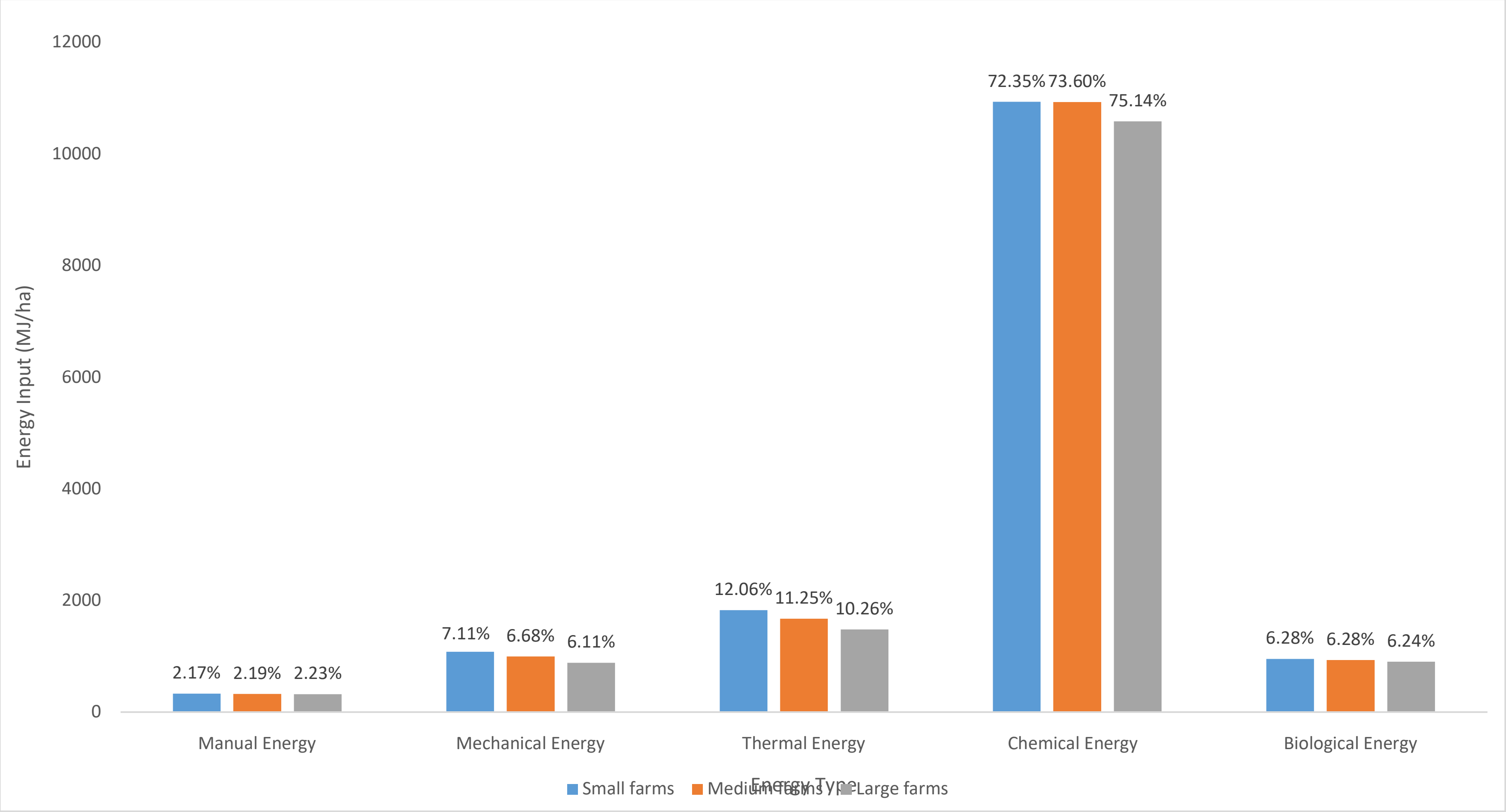


Figure 2: Energy use patterns for Rice Production

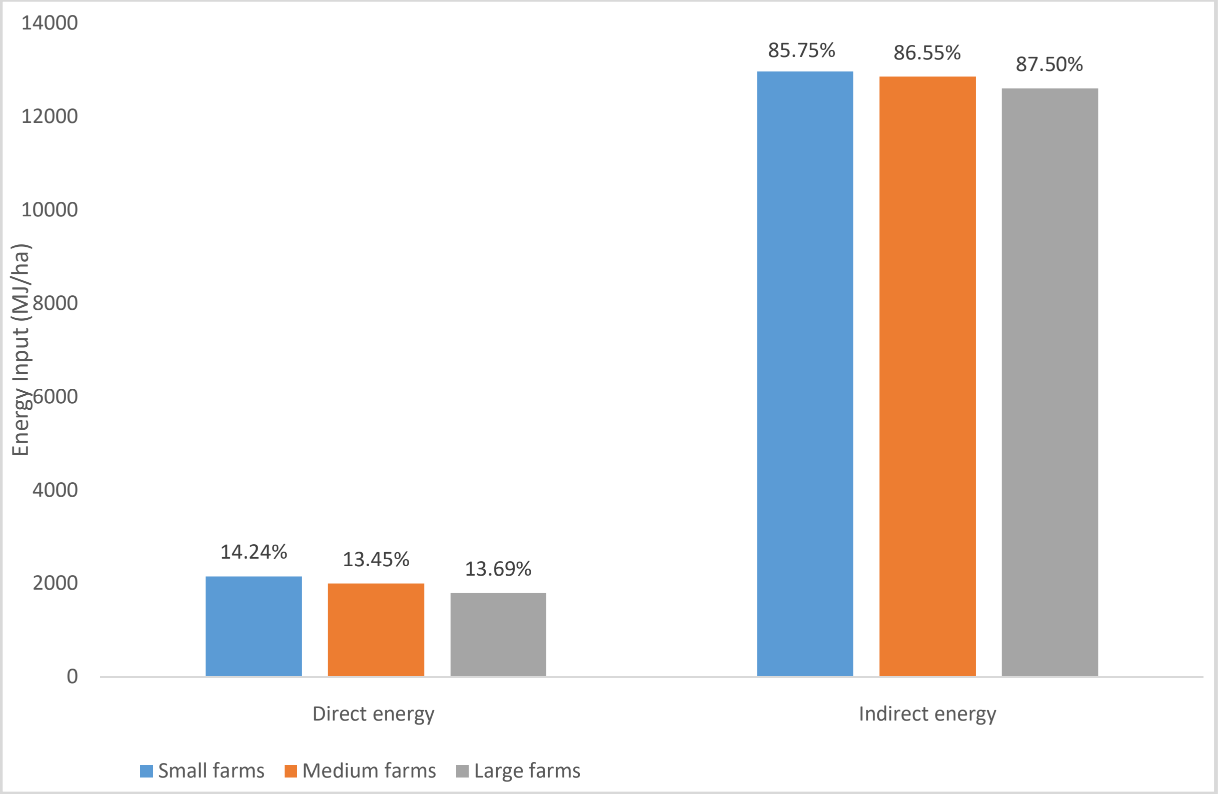


Figure 3: Distribution of Energy Forms in Rice Cultivation

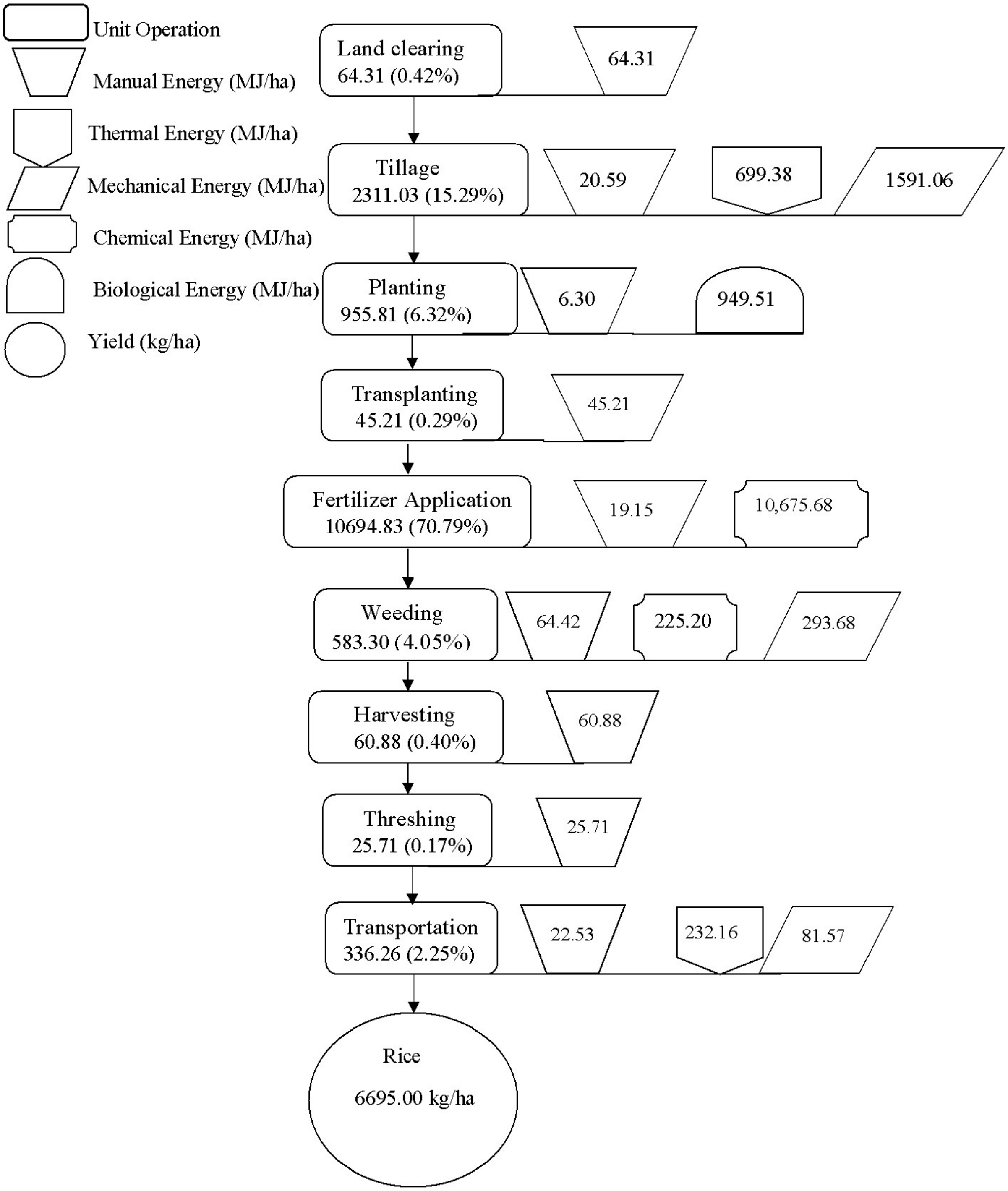


Figure 4:EnergyFlowDiagraminaSmall Rice Farm

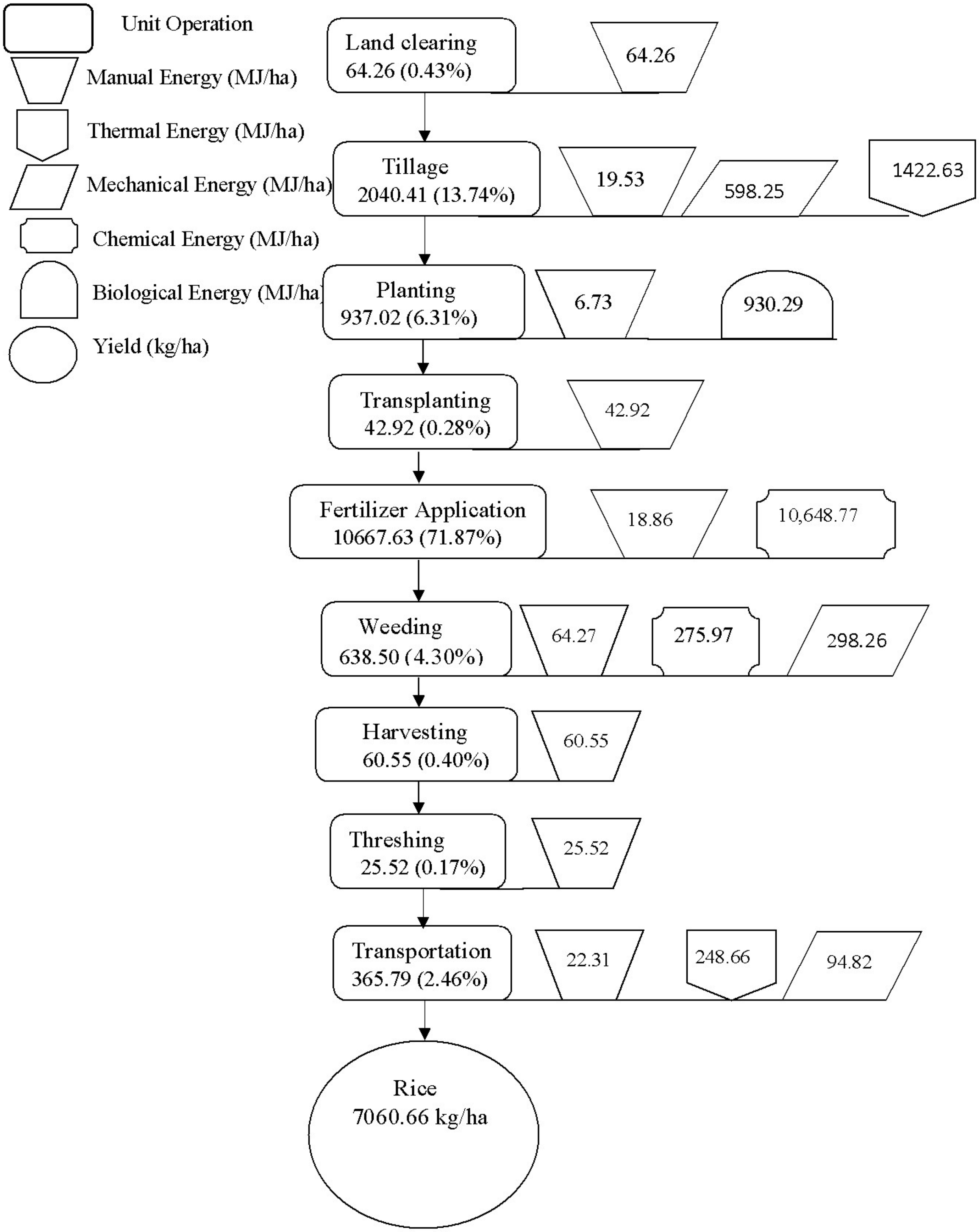


Figure 5:EnergyFlowDiagraminaMedium Rice Farm

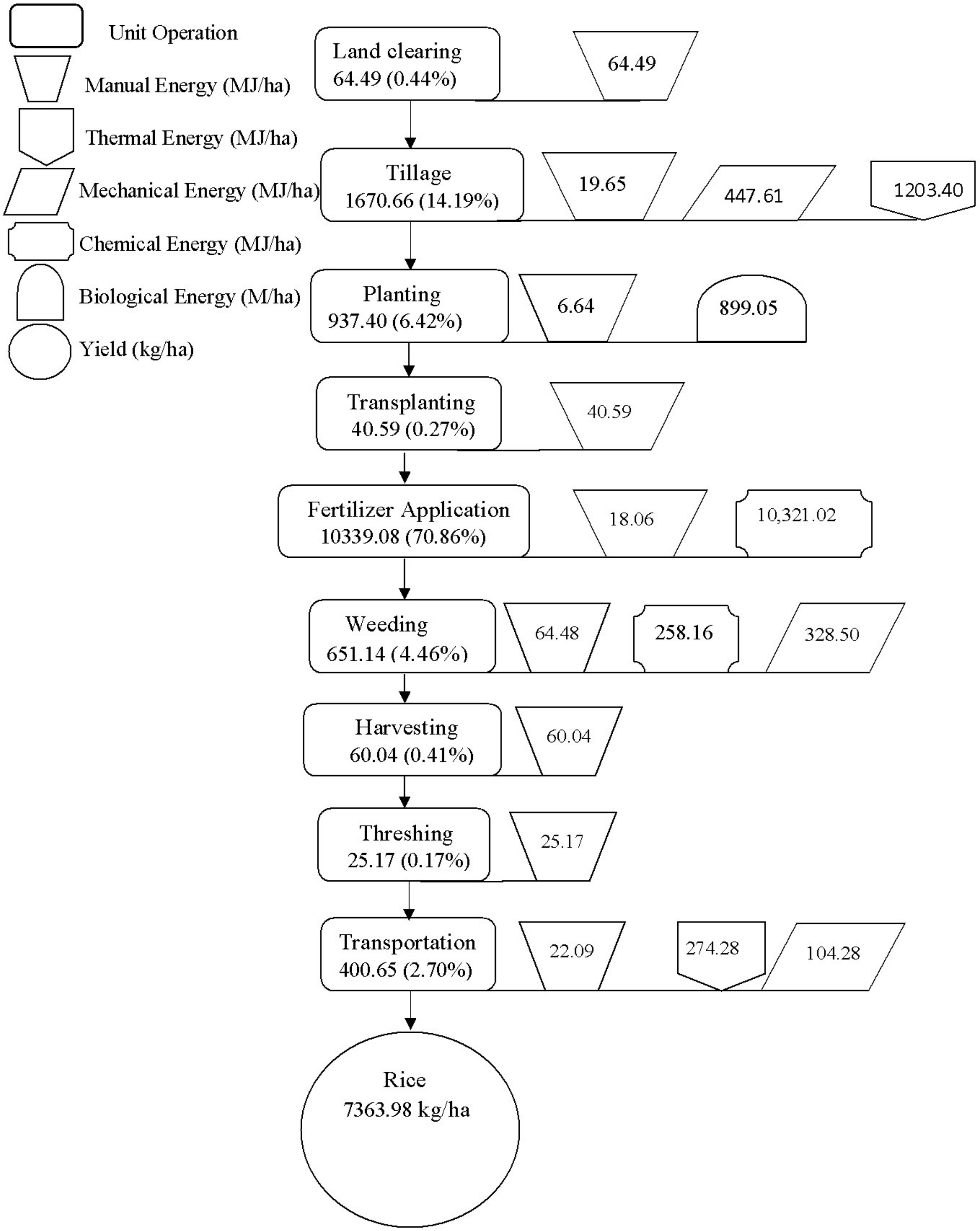


Figure 6:EnergyFlowDiagraminaLarge Rice Farm

Therewere little noticeable variationsinthe energyrequirements forthreshing, harvesting and planting generally in all the farms. This was because the operations were done manually and similar methods of operation were employed.

4.2.4 Energy Use Pattern in Rice Processing

Energy resources used in processing of rice were manual, thermal and electrical energy as shown in Figure 7. Generally in all the farms, it was observed that thermal energy was mostly used. This was followed by electrical and manual energy. In small rice mills, thermal energy contributed about 391.65 MJ amounting to 87.40% ofthetotal energy input.Thisdecreasesto 181.23MJ which was 55.74% of the total energy used inthemediummillsand 179.13MJwhich was 55.87% of the total energy used inthelargemills,as shown in Figure 7.In a study on cashew-nut processing mill in Ibadan, Nigeria, fuel consumption varied from 92GJ to 136GJ, accounting for 74.93% and 89.42% of the total energy consumed, respectively. This shows that the mill depended more on fuel energy than the other two sources of energy (electricity and manual) (Jekayinfa and Bamgboye, 2003). Also, Ibrahim *et al*. (2015) reported thermal energy (wood and diesel fuel) are the major energy input in the rice processing process.

An increaseinelectricalenergyconsumption wasobservedfrom6.86% (30.5 MJ)inthe small millto42.17% (137.09 MJ)and 42.12%(135.05 MJ)inmediumand large mills,respectively. This is because mechanization increases from small to medium to large and there is less dependence on electricity in small mills. The decline of electrical energy from 42.16 % in medium to 42.05% in large mills was due to sophistication of equipmentusedandageoffactories. Manualenergy was the least energy input inall themills. It contributed 25.9,6.72 and 6.41MJ which accounted for 5.79, 2.06%and 1.99% of the total energy used insmall, medium and largemills. The contributions of manual energy decreases from small to large mills due to increase in mechanisation level from small to large mills.

Also, considering theunitoperationsduringproduction(Figures8to10), milling was the most energy intensive operation with 48.10% (215.46 MJ) in small mills, 56.02% (182.09 MJ) in medium mills and 56.12% (179.13.03 MJ)in large mills. Thisclearlyshowsthatmillingwasthemostenergyintensiveprocesses.This is similar to the findings of Olaoye *et al*.(2014) that in the process of wheat milling operation is the most energy intensive operation.

There were noticeable variations in the fuel requirements by the energy intensive equipment during the study.Thisvariationmay beduetolackof adequateattentionor lackof concernfor energyconservation. Although, there are better utilization in medium and large mills, respectively.

In small mills, parboiling consumed 39.82% (178.38MJ), followed by drying which consumed 3.96% (17.76 MJ). Pre-cleaning, sorting and de-stoning consumed13.98, 10.81 and 9.28MJ which accounted for 3.12, 2.41 and 2.07% of the total energy input, respectively,as shown in Figure 8. In medium mills, drying consumed 17.25% (56.1MJ), followed by parboiling of 16.73% (54.38 MJ). Energy consumption for pre-cleaning, sorting and de-stoning was 12.21, 10.29 and 8.77MJ which constituted 3.75, 3.16 and 2.69%of the total energy input, respectively, as shown in Figure 9. Also, in large mills, drying consumed17.27% (55.38MJ), followed by parboiling which consumed16.56% (53.11 MJ). Pre-cleaning, sorting and de-stoning were 11.92, 10.31and 8.75 MJwhich are 3.71, 3.21 and 2.72%, respectively, as shown in Figure 10. Ibrahim *et al*, (2015) identified parboiling, milling and drying as the energy intensive operation in rice processing.

Packaging accounted for the least portion of 0.63% (2.23MJ), 0.36% (1.20MJ) and 0.37% (1.22MJ)in small, medium and large mills, respectively.

4.3 Energy Output in Rice Production

4.3.1 Energy Output in Rice Cultivation

Average rice yield obtained in small, medium and large farms were 6695.0, 7060.65 and 7363.98kg/ha, respectively, as shown in Table 11.These results are within the range reported by Olaleye (2008) that yield of lowland rice in southwest Nigeria ranges between 2 and 8 MT/ha. Also, Oyekami *et al.* (2008) obtained average yield for rice production which varies from 2962 to 7553kg/ha. FARO 44 is the most common rice variety in Nigeria distributed through Growth Enhancement Scheme (GES). It has an expected yield of 7-10 MT per hectare in ideal conditions. However, poor agronomic practices have prevented smallholder farmers from achieving these yields. (Sahel, 2015)

The output energy in small, medium and large farms were 94815.00, 105535.70 11310.30MJ/ha, respectively.Energy output increased from small to large farms, indicating that output energy in medium and large farms was higher than in small farms.

4.3.2 Energy Output in Rice Processing

The average yield in small, medium and large mills were 614.00, 621.00 and 649.00 kg per 1000kg of raw rice, respectively, as shown in Table 13. The trend obtained showed that as the level of mechanization increases from small rice mills to large rice mills, the output from the mills increases in that trend. For rice processing in Nigeria, 1527 kg of paddy was required to produce 100kg of milled rice. The input-output ratio is 1 to 0.65, which is also the conversion factor from paddy to milled rice (Oguntade, 2011).

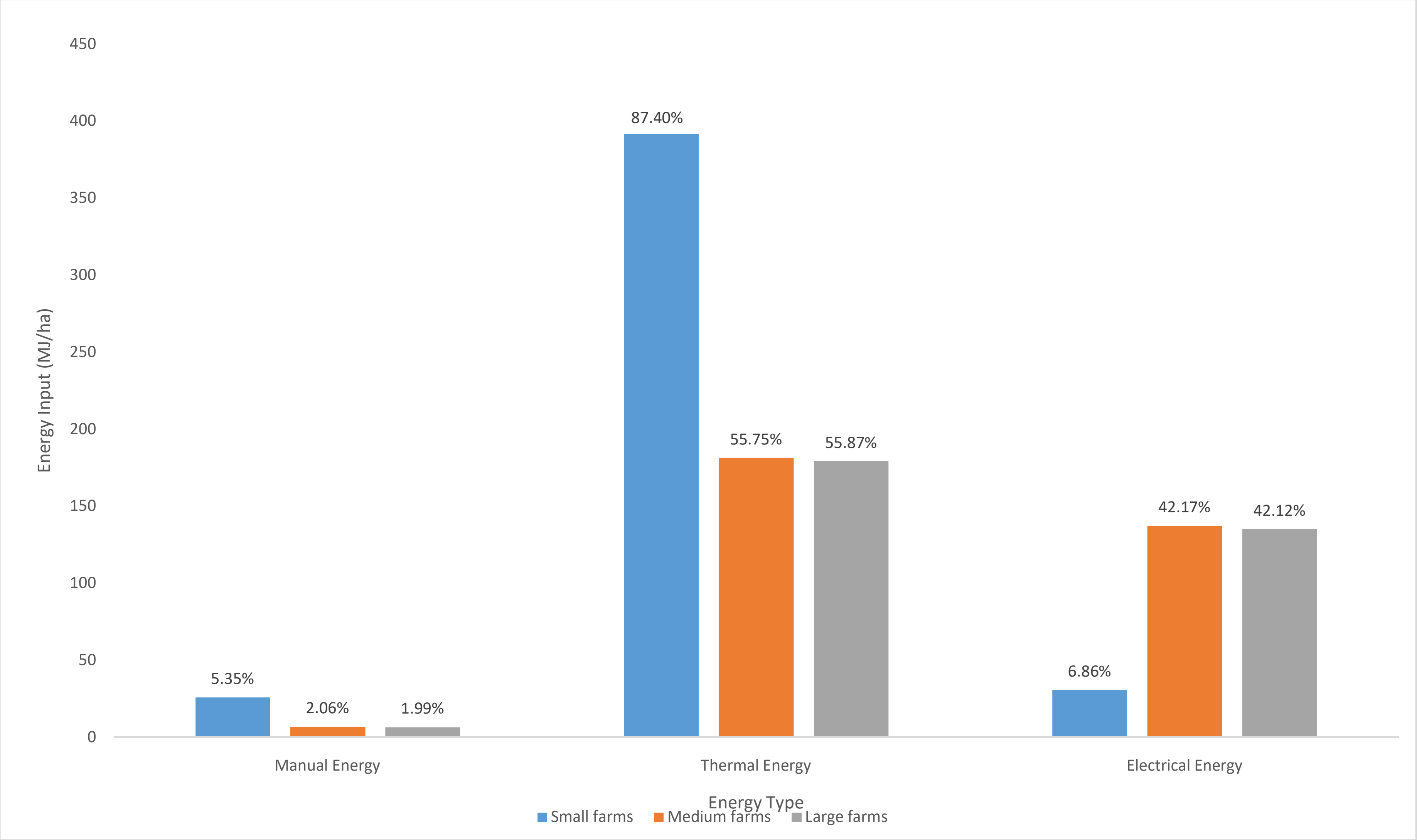


Figure 7: Energy use patterns for Rice processing

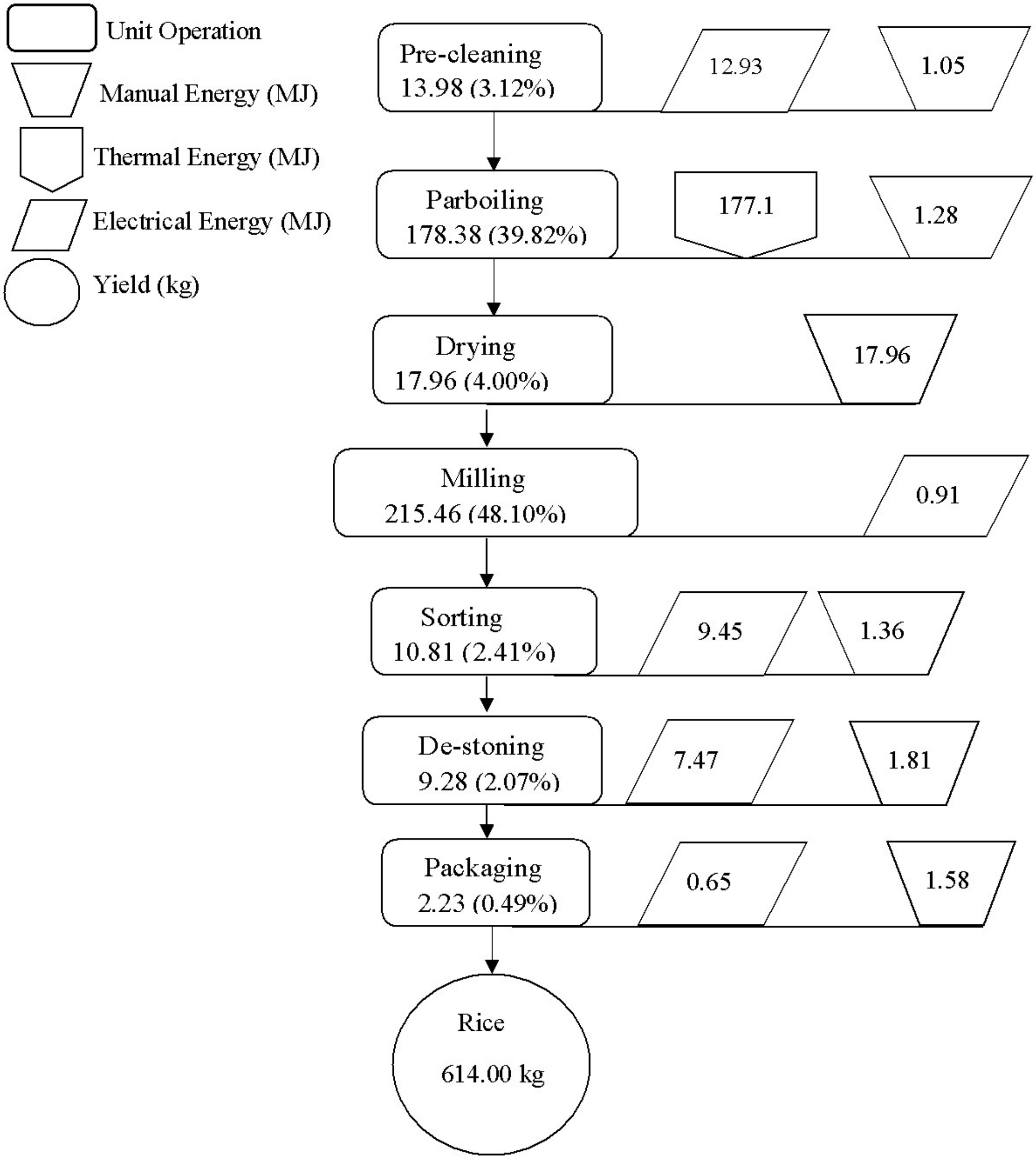


Figure 8:EnergyFlowdiagramina Small Rice Mill

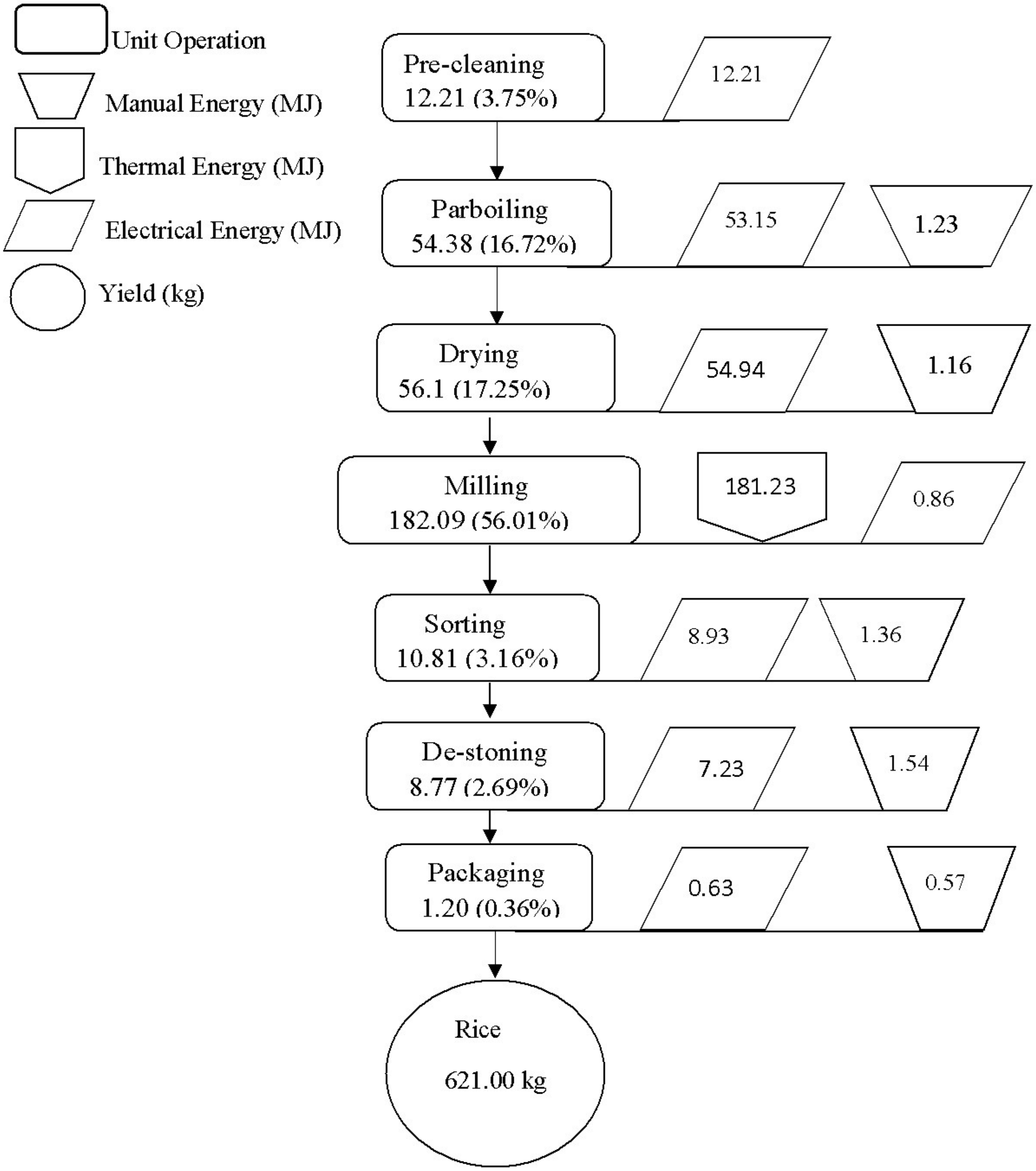


Figure 9:EnergyFlowdiagramina Medium Rice Mill

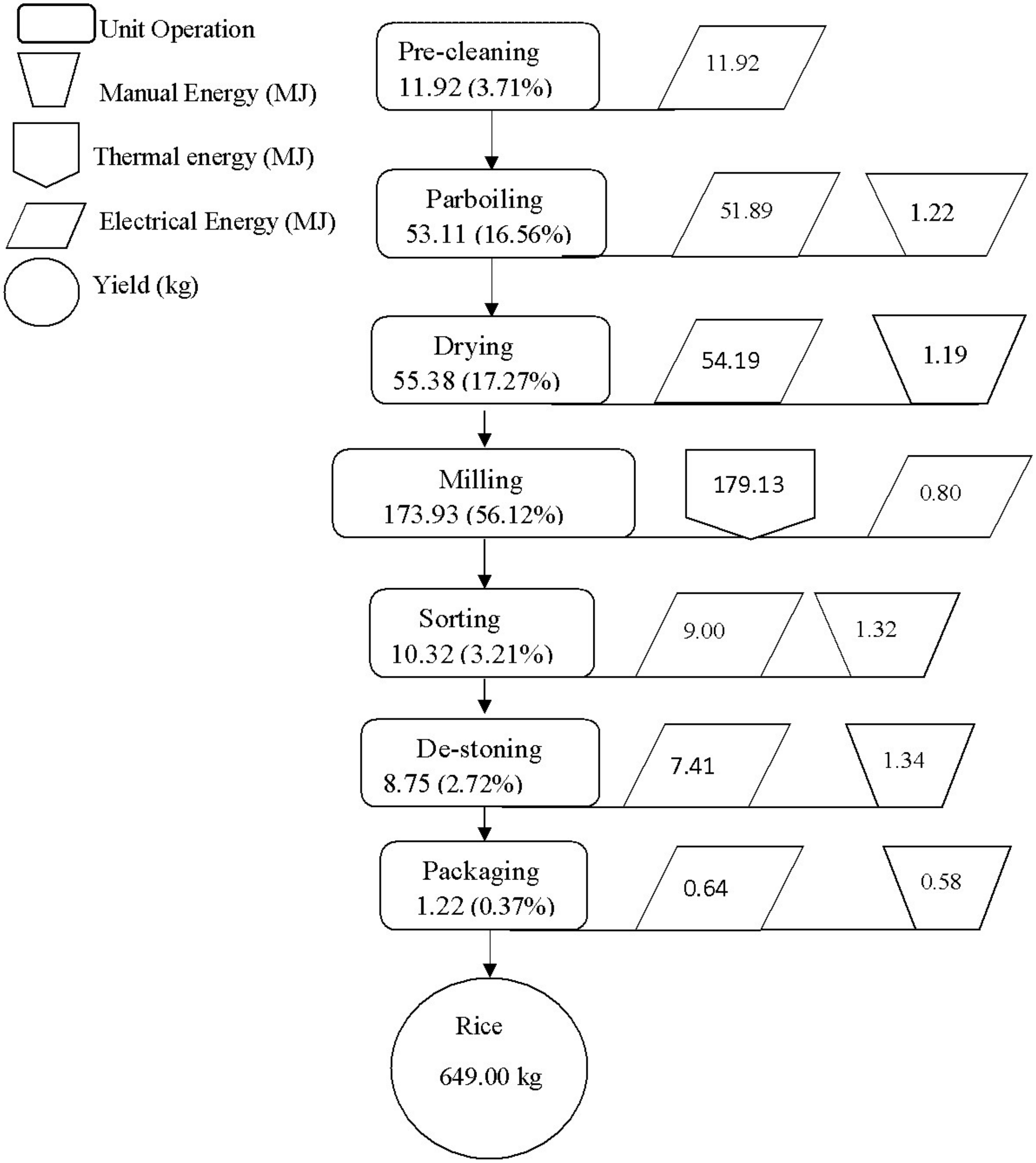


Figure 10:EnergyFlowdiagraminaLarge Rice Mill

4.4 Energy Indicatorsfor the Production of Rice

4.4.1 Energy Indicatorsfor Rice Cultivation

4.4.1.1 The Net Energy

The net energy values for small, medium and large farms were 81839.11, 90693.48 and 93854.18 MJ/ha, respectively, as shown in Figure 11(a). These were considerably closer to the net energy of 86,050 MJ/ha reported in Bangladesh (Iqbal, 2007). High net energy value obtained was attributed to high yield of rice obtained for this study. The net energy value increases from small to large farms indicating that more energy was gained in medium and large farms than in small farms.

4.4.1.2 The Energy Productivity

Energy productivity values for small, medium, and large farms were 0.43, 0.47 and 0.51 kg/MJ, respectively, as shown in Figure 11(b). These indicate that 0.43, 0.47 and 0.51 kg of rice were produced when 1 MJ of energy was usedin small, medium and large farms, respectively. There was an increasein energy productivity from small to large farms, indicating that more kilograms of rice was produced per unit energy (1MJ) input in medium and large farms. In a study conducted on rice production in Nassarwa State Nigeria, energy productivity was 0.3kg/ MJ(Ibrahim and Ibrahim, 2012). Low productivity in their study was attributed to the usage of local rice varieties. However, in a similar research in Australia, it was 1.48kg/MJ (Khan, 2010), indicating almost three-fold higher energy productivity in Australia compared to this study. Low energy relevance in their agro-ecosystems could justify higher productivity on energy consumption in Australia.

4.4.1.3 The Energy Efficiency

Energy efficiencyin small, medium and large farms were 6.41, 7.11 and 7.51, respectively, as shown in Figure 11(c). The energy efficiencies greater than 1.0 indicated that energy was efficiently used.There was an increase in energy efficiency from small to large farms indicating that more energy was used for production in small and medium farms than in large farms.This index in Australia was calculated 6.7 for agro-ecosystems (Khan, 2010). Chamsing *et al.* (2006) in energy consumption analysis for selected crops in different regions of Thailand" obtained energy efficiency of 4.0 and 2.8 for irrigated and rainfed rice, respectively. Low efficiency of rice production in Thailand was as a result of high energy input (20 470.8 MJ/ha) in the production of irrigated rice and low yield in rainfed rice (2,593.7kg/ha) as comparedto obtained for this study.

4.4.1.4 The Agrochemical energy ratio

Agrochemical energy ratios for rice production in small, medium, and large farms were 72.35, 73.60 and 74.11%, as shown in Figure 11 (d). This indicated that more energy was consumed per fertilizer and chemical inputs production. Therewasadecreaseinagrochemical energy ratio fromsmallfarmstothelarge farms.Thisisanindicationof better utilizationof chemical energy (fertilizer and herbicide) inthe mediumandlargescale farmsrespectively. Excessive use of chemical fertilizers energy input in agriculture may create serious environmental consequences such as nitrogen loading in the environment and receiving waters, poor water quality, carbon emissions and contamination of the food chain (Khan *et al*., 2009; Mousavi *et al*., 2012)

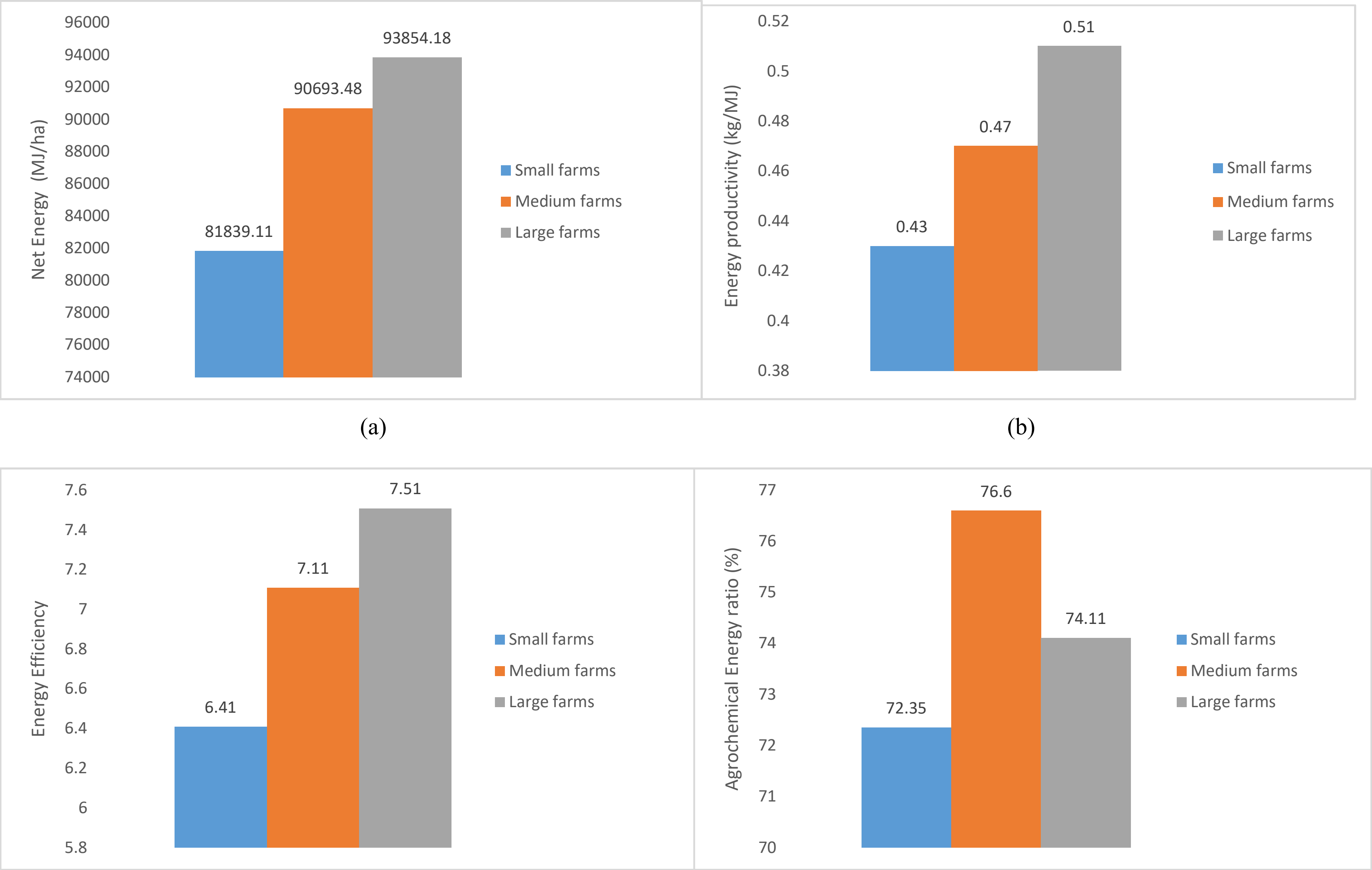
More accurate fertilizer usage according to soil test and plant requirement as well as more application of manures and other natural sources for fertilizing the soil are among suggestions to improve the energy use efficiency without impairing yield and profitability. Also, utilization of alternative sources of energy such as organic fertilizers, farmyard manure may be suggested to reduce the environmental footprints of energy inputs and to obtain sustainable food Production systems.(Pervanchon *et al*., 2002; Pimental and Pimental, 2005).

4.4.2 Energy indicatorsfor rice processing

Energy intensity and energy productivity in small, medium and large rice mills were illustrated in Figure 12 (a). The average energy intensity in small, medium and large mills were 0.70, 0.52 and 0.49 MJ/kg, respectively. There was a decrease in energy intensity from small to large mills. Thisshows that less energy was required to process rice in medium and large mills. The estimated energy intensity for wheat processing was 0.101 MJ/kg (Olaoye *et al*., 2014).Low energy intensity in their study was attributed to high mechanization and productioncapacity (250,000kg/day).

The energy productivity in small, medium and large mills were 1.38, 1.92 and 2.04kg/MJ, respectively, as shown in Figure 12 (b).This means that processed rice grain yield per input energy unit were 1.38, 1.92 and 2.04kg/MJ, respectively. There was an increase in energy productivity from small mills to large mills, indicating that higheroutputper MJ were obtained in medium and large mills than small mills. These was attributed to the level of mechanisation in medium and large mills.

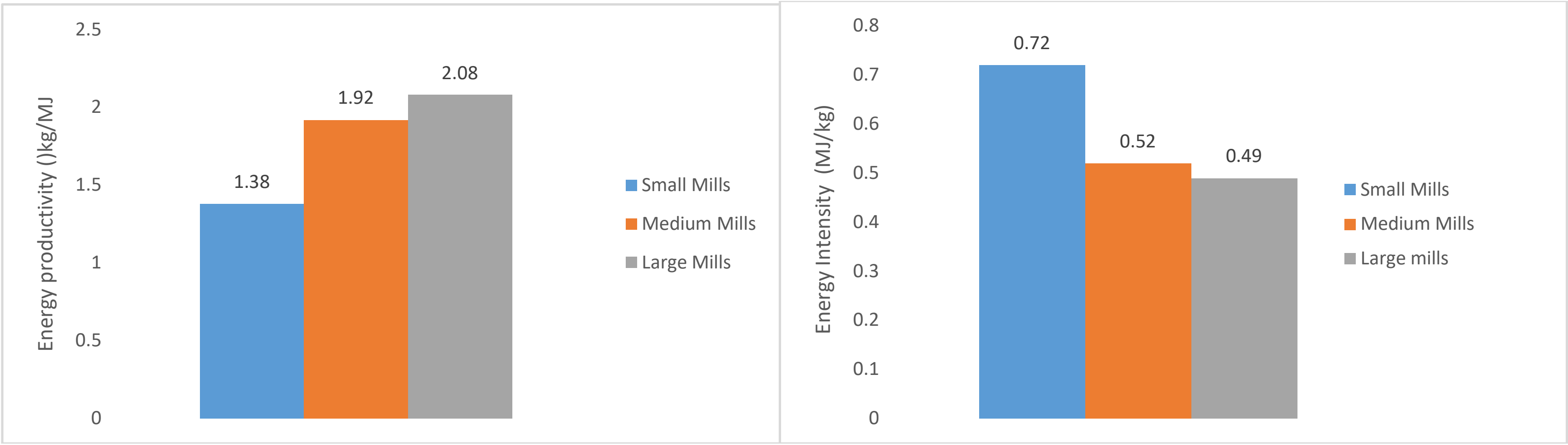
To reduce the energy consumption of the mills, processing equipment that will reduce energy consumption in milling such as the use of large capacity milling machine which can be powered by an electric motor is required. The modern rice mill is somewhat more sophisticated and has a higher initial cost than the steel huller. However, the increased cost is offset by the lower power requirement and operating cost, and increased rice outturn. Also, there is need to reduce energy input in parboiling and drying. The use of an efficient mechanical drying system is an energy saving option for drying operations (Mohammad *et al*., 2009).



(a) (b)

(c) (d)

Figure 11: Energy indicators for Rice Cultivation : Net Energy(a), Energy Productivity (b), Energy Efficiency (c) and Agrochemical energy ratio(d)



(a) (b)

Figure 12: Energy indicators for Rice Processing: Energy Productivity(a) and Energy Intensity (b)

4.5Econometric Model estimate of Rice Production

4.5.1 Econometric Model estimate of Rice Cultivation

The result of the interaction among the input energies as they affects the energy output is as shown in Table 14 and represented by Equation 68. From the equation, the coefficient of determination was 0.99, indicating that all the different energy inputs contributed immensely to the energy output. The variability in the energy inputs could be explained by this model up to 99%. As shown in Table 14, Durbin-Watson value was 2.25, indicating that the model developed was capable of predicting energy output at different energy inputs beyond the two seasons considered in this work. It means that the equation is valid beyond two seasons.

The results revealed that manual, mechanical, thermal, chemical (nitrogen and phosphorous fertilizer) and seed energy inputs were statistically significantly ($p< 0.01$).On the other hand, the impacts of chemical energy input from potassium fertilizer and herbicide on energy output were estimated to be statistically insignificant. Also, all the variables contributed significantly to outputs except potassium fertilizer which shows negative relationship with output.Mobtaker *et al*. (2010) developed an econometric model for barley production in Hamedan province of Iran. They reported that human labour, total fertilizer, machinery, diesel fuel, electricity and water for irrigation energies were the important inputs, significantly contributed to output and machinery energy had highest elasticity.As shown in Equation 68, Nitrogen and phosphorus fertilizer was observed to be the most important energy input that influenced energy output. It had the highest elasticity of 0.86 and 0.44on energy output. The third and fourth important energy inputs were biological and mechanical energy with a coefficient of 0.13 and 0.08, respectively. With respect to the obtained results, an increase of 1% in the consumed energy from chemical (nitrogen fertilizer), chemical (phosphorus fertilizer),biological and mechanical energy, would lead to 0.86, 0.44 0.13 and 0.08% increase in energy output, respectively. The coefficient of thermal and manual were 0.050 and 0.026, respectively, indicating that increase of 1% in these input would lead to 0.050 and 0.026%,increase in energy output respectively.Herbicide and potassium fertilizer (chemical energy) on the other hand were the energy input that least influenced the output of rice, withcoefficient of 0.0043 and -0.064, respectively, as shown by Equation 68.

Phosphorus fertilizer and manual energy had the major Marginal Physical Productivity value (MPP) of 6.36 and 1.08, respectively. It is followed by seed and mechanical energy with MPP value of 1.05 and 0.8, respectively, as shown in Table 14. This implies that an additional use of 1 MJ ha^{-1} from each of the seed, manual energy and mechanical would lead to an additional increase in yield of rice by 1.08, 1.05 and 0.8kg ha^{-1}, respectively. In other words, there is high potential for increasing output by additional use of these inputs for rice production in the surveyed region.

Table 14: Econometric Estimation Results of Energy inputs for Rice Cultivation

Endogenous variable:	**Rice yield (Y_i)**	
Exogenous variables	Coefficients (α_1)	MPP
$Model\ I: \ln Y_i = \alpha_1 lnX_1 + \alpha_2 lnX_2 + \alpha_3 lnX_3 + \alpha_4 lnX_4 + \alpha_5 lnX_5 + \alpha_6 lnX_6 + \alpha_7 lnX_7 + \alpha_8 lnX_8 + e_i$		
1. Manual Energy (X_1)	0.03	1.08
2. Thermal Energy (X_2)	0.05	0.33
3. Mechanical Energy (X_3)	0.08	0.82
4. Biological Energy (X_4)	0.14	1.05
5. Chemical Energy N (X_5)	0.86	0.62
6. Chemical Energy P_2O_5 (X_6)	0.44	6.36
7. Chemical Energy K_2O (X_7)	-0.64	-11.20
8. Chemical Energy Herbicide(X_8)	0.003	0.10
9. Yeild (Y_i)		
Return to Scale (RTS)	0.96	
Durbin Watson Test (DW)	2.25	
R-square	0.99	

$$Model\ I: \ln Y_i = 0.03\ lnx_1 + 0.05\ lnx_2 + 0.08\ lnx_3 + 0.14\ lnx_4 + 0.86\ lnx_5 + 0.44\ lnx_6 - 0.64\ lnx_7 + 0.003\ lnx_8 \qquad R^2 = 0.99 \tag{68}$$

Table 15: Econometric Estimation Results for Direct and Indirect Energy for Rice Cultivation.

Endogenous variable: **Exogenous variables**	**Rice yield ($\mathbf{Y_i}$)** Coefficients (β_1)	 MPP
$Model\ II : \ln Y_i = \beta_1 lnDE + \beta_2 lnIDE + e_i$		
1. Direct Energy (DE)	0.05	0.23
2. Indirect Energy (IDE)	0.90	0.50
Return to Scale (RTS)	0.95	
Durbin Watson Test (DW)	2.32009	
R-square	0.99	

$$Model\ II : \ln Y_i = 0.04726\ lnDE + 0.89942\ lnIDE \qquad R^2 = 0.99 \qquad (69)$$

On the other hand, the MPP value of potassium fertilizer was found negative, indicating that there was excessive usage of these inputs for rice production andadditional use of this input will contribute negatively to the output in the surveyed region. This would result to energy dissipation and as well imposing negative effects to the environment and human health. The energy input can be reduced by reducing the quantity of potassium fertilizer input and supplement with an organic fertilizer.Mobtaker *et al.*(2010) analysed the sensitivity of energy inputs on barley productivity. They reported that the major MPP was from human labor energy (7.37), followed by machinery energy (1.66). Also, Ramedani*et al.* (2012) examined the sensitivity of energy inputs on canola production. They reported that seed had the highest MPP value (13.45) and followed by human labor (2.69).

The value of Return to Scale (RTS) for model II (equation 102) was 0.96, as shown in Table 14. The value lower than one (1) implies decreasing Returns to Scale (DRS). This implied that 1% increase in the total energy inputs would leads to 0.96% increase in the rice yield. Therefore, increase in the total energy input would not increase the output in the surveyed region.

The effect of direct and indirect energies (DE and IDE) on output was also established as shown in Equation (69). From Equation 69, the coefficient of determination was 0.99, indicating that all the different energy inputs contributed immensely to the energy output. The variability in the energy inputs could be explained by this model up to 99%.

Direct and indirect energies were statistically significant ($p< 0.01$). Thecoefficient of DE and IDE were estimated as 0.05 and 0.90, respectively, as Equation 69. This imply that 1% increase in direct and indirect energy inputs would led to 0.05 and 0.90 increase in yield, respectively. This indicated that the indirect energy has higher influence on energy output than direct energy.Similar results can be seen in the study of Hatirli *et al.*(2005) for greenhouse tomato production.

The Durbin- Watson (DW) value for the model was 2.32 as shown in Table 15.The value closer to two (2) indicated that the developed model was capable of predicting energy output at different input for the two seasons and beyond. The marginal physical productivity value (MPP) of indirect energy and direct energy were 0.50 and 0.22, respectively, as shown in Table 15. This implies that an additional use of 1 MJ ha^{-1} from each of the indirect energy and direct would lead to an additional increase in yield of rice by 0.50 and 0.22kg ha^{-1}, respectively.

The value of Return to Scale (RTS) for model II (Equation 69) obtained was 0.94 as shown in Table 15. The value lower than one implies decreasing returns to scale (DRS). This implied that 1% increase in the total energy inputs would leads to 0.94% increase in the rice yield. Therefore, increasing the total energy input would not increase the output in the surveyed region.

4.5.2 Econometric Model estimate of Rice Processing

The results of the interaction among the input energy as they affect the energy output are as shown in Table 16 and represented by Equation 70. From the Equation, the coefficient of determination was 0.98, indicating that all the different energy inputs contributed immensely to the energy output. The variability in the energy inputs could be explained by this model up to 98%. FromTable 16, Durbin-Watson value was 2.85, indicating that the model developed was capable of predicting energy output at different energy inputs beyond the two seasons considered in this work. It means that the equation is valid beyond two seasons.

Electrical and manual energy inputs were statistically significant ($p<0.01$). Moreover, from equation 70, manual energy input had the highest coefficient of 0.81 on energy output, indicating that an increase in manual energy input by 1% will lead to 0.81% energy output. Thermal energy input was found to be statistically insignificant ($p>0.01$), indicating change in this input would not have any significant change in the output.

Thesensitivity analysis of energy inputs on rice yield shows that manual energy had the major MPP value of 55.56, followed by electrical energy of 4.53 as shown by Table 16. This implies that an additional use of 1 MJ ha^{-1} from each of the manual energy and electrical energies would lead to an additional increase in yield value of rice by 55.65 and 4.53 kg, respectively,as shown in Table 16.

The value of Return to Scale (RTS) for model III obtained was 1.78. The value greater than unity (1) implies increasing Returns to Scale (IRS). This indicated that an increase in the input by 1% will lead to an increase in the output by 1.78 percent. In other words, there is high potential for increasing output by additional use of these inputs for maize production in the surveyed region.

The effect of the direct and indirect energy (DE and IDE) input on the output in rice processing are as shown in equation 71. The R^2(coefficient of determination) of the model was 0.94, as shown in Table 17. This implies that all the explanatory variables included in the regression equation had contributed to the energy output by 94%. The direct and indirect energy were statistically significant ($p<0.01$). The impact of indirect energy was more than the direct energy on energy output. Durbin-Watson value was 2.85, indicating that the model developed was capable of predicting energy output at different energy inputs beyond the two seasons considered in this work. It means that the equation is valid beyond two seasons.

Thesensitivity analysis of energy inputs on rice yield shows that indirect and direct energy inputs have the marginal physical productivity values (MPP) of 3.23 and 1.41, respectively,as shown in Table 17. This implies that an additional use of 1 MJ from each of the indirect energy and direct energy inputs would lead to an additional increase in yield of rice by 3.23 and 1.41 kg , respectively, indicating that indirect energy has higher influence on output than direct energy.

The value of Return to Scale (RTS) for model IV obtained was 1.24. The value greater than 1 implies increasing Returns to Scale (IRS). This indicates that an increase in the input by 1% will lead to increase in the output by 1.24 percent. In other words, there is high potential for increasing output by additional use of these inputs for rice processing in the surveyed region.

4.6 Economic Analysis of Rice Production

4.6.1 Cost of Energy Input in cultivation of Rice

The cost input incultivation for small, medium and large farm are shown in Table 18. Total amount spent on rice cultivation varied from ₦108249.00 to ₦110205.00 in small farms and it varied from ₦107255.00 to ₦108780.00 and ₦103105.00 to ₦103565.0 in medium and large farms, respectively, as shown in Table 21. The variation was caused majorly by the difference in price and quantity of biological, thermal and chemical energy input.

The average total cost of producing rice per hectare in small, medium and large farm were ₦109385.30, ₦107930.80 and ₦103383.00, respectively as shown in Table 19.Thereisadecreaseinthetotalcost of producing rice aswe movefromsmallfarmstolargefarms.Thisisanindicationof better utilizationof energyinthe mediumandlargescale farms. Cost input obtained for this study was lower to the findings of Lawal *et al.* (2012) who reported that ₦117, 827.60 was used in the production of one hectare of rice. High cost input in their study was attributed to high manual energy input.

4.6.2 Cost of energy Input in Rice Processing.

The cost input and yield for small, medium and large mills were presented in Table 20.Total amount spent on 1000kg of rice varied from ₦10995.38.00 to ₦12163.05 in small mills and it varied from ₦10257.20 to ₦10301.88 and ₦9852.30 to ₦9932.35.0 in medium and large mills, respectively, as shown in Table 20. In small mills, the variation was caused majorly by difference in the mode of operation and level of mechanisation. While, the variations in medium and large mills were due to the differences in the quantity of rice processed, sophistication of equipment used and age of factories.

The average total cost of processing 1000 kg of rice for respective categories were ₦12251.86, ₦10276.51 and ₦9859.10 as shown in Table 21. This shows that the cost of processing rice in the surveyed region decreases has the level of mechanization and processing scale increases.

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Table 16: Econometric Estimation results of Rice Processing

Endogenous variable:	**Rice yield (Y_i)**	
Exogenous variables	Coefficients (α_1)	MPP
$Model\ III : \ln Y_i = \alpha_1 lnX_1 + \alpha_2 lnX_2 + \alpha_3 lnX_3 + e_i$		
1. Electrical Energy (X_1)	0.62	4.53
2. Manual Energy (X_2)	0.81	55.65
3. Thermal Energy (X_3)	0.35	1.13
Return to Scale (RTS)	1.78	
Durbin Watson Test (DW)	2.85	
R-square	0.98	

$Model\ III : \ln Y_i = 0.62lnx_1 + 0.81lnx_2 + 0.35lnx_3 R^2 = 0.98$ (70)

Table 17: Econometric Estimation results for Direct and indirect Energy for rice Processing.

Endogenous variable:	**Rice yield ($\mathbf{Y_i}$)**	
Exogenous variables	Coefficients (β_1)	MPP
$Model\ IV : \ln Y_i = \beta_1 lnDE + \beta_2 lnIDE + e_i$		
1. Direct Energy (DE)	0.19	1.41
2. Indirect Energy (IDE)	1.05	3.23
Return to Scale (RTS)	1.24	
Durbin Watson Test (DW)	2.85	
R-square	0.94	

$$Model\ IV : \ln Y_i = 0.19 lnDE + 1.04 lnIDE \qquad R^2 = 0.94 \tag{71}$$

Table 18: Cost of Energy Input and Output in the Cultivation of Rice (₦/ ha)

	Cost Input (₦/ ha)								
Unit Operation	**Small farms**			**Medium farms**			**Large farms**		
	Farm 1	**Farm 2**	**Farm 3**	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 1**	**Farm 2**	**Farm 3**
Land clearing									
Manual energy	14650.00	14500.00	14650.00	14500.00	14250.00	14250.00	14000.00	14250.00	14250.00
Tillage									
Manual energy	6500.00	6600.00	6500.00	6400.00	6400.00	6400.00	6400.00	6400.00	6200.00
Mechanical energy	1250.00	1250.00	1250.00	1250.00	1250.00	1250.00	1200.00	1200.00	1250.00
Thermal energy	4000.00	3900.00	3950.00	3790.00	3827.50	3790.00	3780.00	3785.00	3665.00
Planting									
Manual energy	1100.00	1200.00	1200.00	1000.00	1000.00	1000.00	1000.00	1100.00	1000.00
Biological energy	2650.00	2600.00	2500.00	2650.00	2700.00	2750.00	2500.00	2250.00	2500.00
Transplanting									
Manual energy	6500.00	6000.00	6250.00	7250.00	7250.00	7250.00	7000.00	6750.00	7000.00
Fertilizer application									
Manual energy	1500.00	1400.00	1500.00	1400.00	1500.00	1400.00	1200.00	1300.00	1300.00
Chemical energy N	12800.00	13000.00	12800.00	13000.00	12000.00	12600.00	12000.00	12000.00	12200.00
P_2O_5	6600.00	6000.00	6600.00	6000.00	6600.00	6000.00	6000.00	6000.00	6000.00
K_2O	6600.00	6000.00	6600.00	6000.00	6600.00	6000.00	6000.00	6000.00	6000.00
Weeding									
Manual energy	14750.00	14000.00	15250.00	14500.00	14000.00	14750.00	13000.00	13250.00	13000.00
Chemical energy (Herbicide)	3600.00	3700.00	3400.00	3500.00	3400.00	3400.00	3600.00	3600.00	3600.00
Mechanical energy	300.00	350.00	325.00	325.00	350.00	350.00	325.00	300.00	325.00
Harvesting									
Manual energy	14000.00	14250.00	14000.00	14500.00	14250.00	13750.00	13250.00	13500.00	13250.00
Threshing									
Manual energy	8250.00	8250.00	8000.00	7500.00	7000.00	7000.00	7000.00	7000.00	7250.00
Transportation									
Manual energy	2900.00	2900.00	2800.00	2750.00	2850.00	2850.00	2600.00	2550.00	2500.00
Thermal energy	455.00	449.00	427.00	765.00	730.00.00	765.00	650.00	644.00	675.00
Mechanicalenergy	1800.00	1900.00	1700.00	1700.00	1700.00	1700.00	1600.00	1600.00	1600.00
Cost of energy Input (₦/ha)	110205.00	108249.00	109702.00	108780.00	107657.50	107255.00	103105.00	103479.00	103565.00
Yield (kg/ha)	6500.00	6550.00	6960.00	7000.00	6860.00	7322.00	7200.00	7450.00	7442.00
Cost Output (₦ /ha)	251000.00	262000.00	278400.00	280000.00	274400.00	292880.00	288000.00	298000.00	297680.00

Table 19: Average Cost of energy Input and Output in the Cultivation of Rice (₦/ ha)

	Cost Input (₦/ha)		
Unit Operation	**Small farms**	**Medium farms**	**Large farms**
Land clearing			
Manual energy	14600.00	14333.34	14166.67
Tillage energy			
Manual energy	6533.00	6433.33	6333.33
Mechanical energy	1250.00	1250.00	1216.66
Thermal energy	3950.00	3802.50	3743.33
Planting			
Manual energy	1166.00	1000.00	1033.33
Biological energy	2583.00	2700.00	2416.66
Transplanting			
Manual energy	6250.00	7250.00	6916.66
Fertilizer application			
Manual energy	1466.66	1433.33	1266.66
Chemical energy N	12866.67	12533.33	12066.67
P_2O_5	6400.00	6200.00	6000.00
K_2O	6400.00	6200.00	6000.00
Weeding			
Manual energy	14666.67	14416.67	13083.33
Chemical energy (Herbicide)	3566.66	3433.33	3600.00
Mechanical energy	325.00	341.66	316.66
Harvesting			
Manual energy	14083.00	14166.67	13333.33
Threshing			
Manual energy	8166.66	7166.66	7083.33
Transportation			
Manual energy	2866.66	2816.66	2550.00
Thermal energy	443.66	753.33	656.33
Mechanical energy	1800.00	1700.00	1600.00
Cost of Energy Input (₦/ha)	109385.30	107930.80	103383.00
Yield (kg/ha)	6695.00	7060.66	7364.00
Cost Output (₦ /ha)	263800.00	281926.70	294559.50

Table 20: Cost of energy Input inrice processing operations.

	Cost Input (₦)								
Unit Operation	**Small mill**			**Medium mill**			**Large mill**		
	Mill 1	**Mill 2**	**Mill 3**	**Mill 1**	**Mill 2**	**Mill 3**	**Mill 1**	**Mill 2**	**Mill 3**
Pre- cleaning									
Electrical energy	153.1	152.15	149.15	151.6	140.0	140.0	140.0	124.3	145.0
Manual energy	600	600	600	-	-	-	-	-	-
Parboiling									
Electrical energy	-	-	-	340	336.5	340	327	321	320
Thermal energy	1000.00	1000.00	900.00	-	-	-	-	-	-
Manual energy	2200.00	2200.00	2200.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
Drying									
Electrical energy				378.00	360.00	370.0	370.00	375.00	372.00
Manual energy	1500	1500	1500	800	800	800	800	800	800
Milling									
Thermal energy	1285	1316	1271	1087.1	1078.55	1076.72	951.35	1029.35	971.5
Manual energy	2000.00	2000.00	2000.00	2000.00	2000.0	2000.0	2000.0	2000.0	2000.00
Sorting									
Electrical energy	57.28	57.00	56.90	57.90	57.10	57.05	57.00	57.00	57.10
Manual energy	1200.00	1200.00	1200.0	1200.00	1200.0	1200.00	1200.00	1000.00	1000.0
De-stoning									
Electrical energy	---	---	57.00	57.28	57.05	57.00	57.00	57.00	58.70
Manual energy	---	---	1200.00	1200.00	1200.00	1200.00	1000.00	1000.00	1100.00
Packaging									
Electrical energy	---	---	29.00	30.00	28.00	30.00	30.00	29.00	28.00
Manual energy	1000.00	1000.00	1000.00	1000.0	1000.00	1000.0	1000.00	1000.0	1000
Cost of energy Input (₦)	10995.38	11025.15	12163.05	10301.88	10257.2	10270.77	9932.35	9792.65	9852.3
Yield (kg)	612.5	615	615.5	621	627.5	620	651	645	652

Table 21: Average Cost of Energy Input in Rice processing operation.

	Cost Input (₦)		
Unit Operation	**Small Mill**	**Medium Mill**	**Large Mill**
Pre- cleaning			
Electrical energy	151.46	146.86	136.43
Manual energy	600.00		
Parboiling			
Electrical energy		338.83	322.00
Thermal energy	966.66		
Manual energy	2200.00	2000.00	2000.00
Drying			
Electrical energy		369.33	372.33
Manual energy	1500.00	800.00	800.00
Milling			
Thermal energy	1290.66	1080.79	984.06
Manual energy	2000.00	2000	2000
Sorting			
Electrical energy	57.00	57.08	57.03
Manual energy	1200.00	1200.00	1066.6
De-stoning			
Electrical energy	57.00	57.11	57.56
Manual energy	1200.00	1200.00	1033.00
Packaging			
Electrical energy	29.00	29.25	29.00
Manual energy	1000.00	1000.00	1000.00
Cost of Energy Input (₦)	12251.86	10279.51	9859.1
Yield (kg)	614.00	621.00	649.15
Yield cost (₦)	101284.00	104970.00	112427.90

4.6.3 Cost of EnergyInput Pattern in Rice Cultivation

It was observed that in all the farms, amount spent on manual energy resources was the highest. Amount spent on manual energy in small, medium and large farms were ₦69798.65, ₦69016.66 and ₦65766.64 amounting to 63.81, 63.94 and 63.61% of the total cost input, as shown in Figure 13. There is a decrease in the amount spent on manual energy from small to large farm. This is attributed to increase in level of mechanisation. Manual energy cost per hectare reported by Lawal *et al.* (2012) was higher (₦85495.00.) than what was obtained in this study. Also,this is similar to what was obtained for NERICA production in the Southern Guinea Savanna of Niger State, Nigeria (Chamsing, *et al.,* 2006). Manual energy cost reported for NERICA production by Lawal *et al.* (2013) was 68% of the total cost production. High cost of manual energy in their study was attributed to low level of mechanisation. All the operation in their study was done manually. To increase the profitability of rice production the study area, effort should be made to increasing level of mechanization.

Amount spent on chemical energy in small, medium and large farms were ₦29233.29, ₦28366.66 and ₦27666.67which accounted for 26.72, 26.28 and 26.76%, respectively. There was variation in the amount spent on chemical energy from small to large farms. The variation was due to different quantity of fertilizer and herbicide used. Price of fertiliser and herbicide also varies, thus contributed to the variation.

In small farms,Amount spent on thermal and mechanical were₦4393.66(4.01%) and ₦3375.00 (3.08%), respectively, as shown in Figure 13. In medium farms, ₦ 4555.83 (4.22%) and ₦3291.66 (3.04%) of the total cost, respectively. Also, in large farms, amount spent on these energy resources were ₦4399.66 (4.25%) and₦3133.32 (3.30%), respectively. Low amount spent on mechanical and thermal energy in this study was attributed to low mechanisation.Amount spent on biological energy in small, medium and large farms were ₦2583.00, ₦2700.00 and ₦2416.66 which accounted for 2.36, 2.50 and 2.33%, respectively. These was closer to ₦25200.00 obtained from rice in Kaduna, Nigeria (Ben-chendo, *et al.* 2016).

Considering theunitoperationsduringproductionas shown in Figures14to16, the maximum cost input inallthethreefarms were from fertilizer application. Fertilizer application shared the highest cost input of ₦27133.33, ₦26366.66, ₦25333.33 accounted for 24.80, 24.42 and 24.17% ofthetotalinputenergy in small,mediumandlarge farm, respectively. This clearlysupports the previous finding thatfertilizer applicationisthemostenergyintensiveprocesses in rice production. Therewerenoticeablevariationsin thecost of applying fertilizer from small to large farms.Thisvariationwas duetovariation in cost of fertilizer and transporting it to the farm.A bag of 50kg fertilizer cost between ₦5500.00 to ₦6000.00 when this study was carried out. Nwalieji (2016) reported that amount spent on fertilizer application when 0.5ha of rice was cultivated using broadcasting and transplanting methods was ₦12,000.00.

Inthesmallfarms, average cost incurred on weeding, land clearing and harvesting operations were ₦18558.33, ₦14600.00 and ₦14083.00, which accountedfor17.00, 13.34 and 12.87%ofthetotalinputcost, respectively. Inthe medium farms, average cost incurred on weeding, land clearing and harvesting operations were₦18191.66 (16.85%), ₦14333.34 (13.28%) and ₦14166.67 (13.12%), respectively, while₦16999.99, (16.64%), ₦14166.67 (13.70%) and ₦1333.33 (12.28%) were spent onthe same operations inlargefarms. This is similar to the finding of Lawal *et al.* (2013) that the three operations that required high level of labour cost in rice cultivation were land preparation, weeding and harvesting.

Amount spent on tillage operations in small, medium and large farms were ₦11733.00, ₦11485.83 and ₦11293.32, respectively. These accounted for 10.72, 10.64 and 10.92% of the total cost of producing rice in the region surveyed. There was a decrease in the amount spent on tillage operation from small to large farms. The decrease was as a result of mechanization level which increases from small to large farms.

As shown in Figure 14, the average amount spent on threshing, transplanting and transportation in small farms were ₦8166.66, ₦6250.00 and ₦5110.32, respectively. These accounted for 7.46, 5.71 and 4.60% of the total production cost of producing rice, respectively, in the region surveyed. There was little or no observed variation in the entire small farms surveyed.

In medium farms, average costspent on transplanting, threshing and transportation₦7250.00, ₦7166.66 and ₦5269.99 were, respectively. These contributed 6.71 6.64 and 4.88% of the total cost of cultivating rice in the region surveyed, respectively, as shown in Figure 15.

From Figure 16, amount spent on threshing, transplanting and transportation operations in large farms were ₦7083.33, ₦6916.66 and ₦4806.33 which was 6.85, 6.69 and 4.64% of the total cost input, respectively. The minimum cost input was spent on planting in all the farms. Amount spent planting in small, medium and large farms were ₦3749.00, ₦ 3700.00 and ₦4449.99, respectively, which accounted for 3.43, 3.42 and 3.33% of the total cost.

4.6.4 Energy Cost Pattern in Rice Processing

Manual energy cost contributed most to the total cost of rice processing inallthethreemills.Amount spent per 1000 kg on manual energy in small, medium and large millswere₦9700.00, ₦8200.00 and ₦7899.00 which accounted for 79.17, 79.77 and 80.13% ofthetotalcost in small,mediumandlarge mills, respectively,as shown in Figure 17. There is a decrease in the cost of manual energy input from small to large mills. The decrease can also be attributed to increasing level of mechanization as we move from small to large mills.

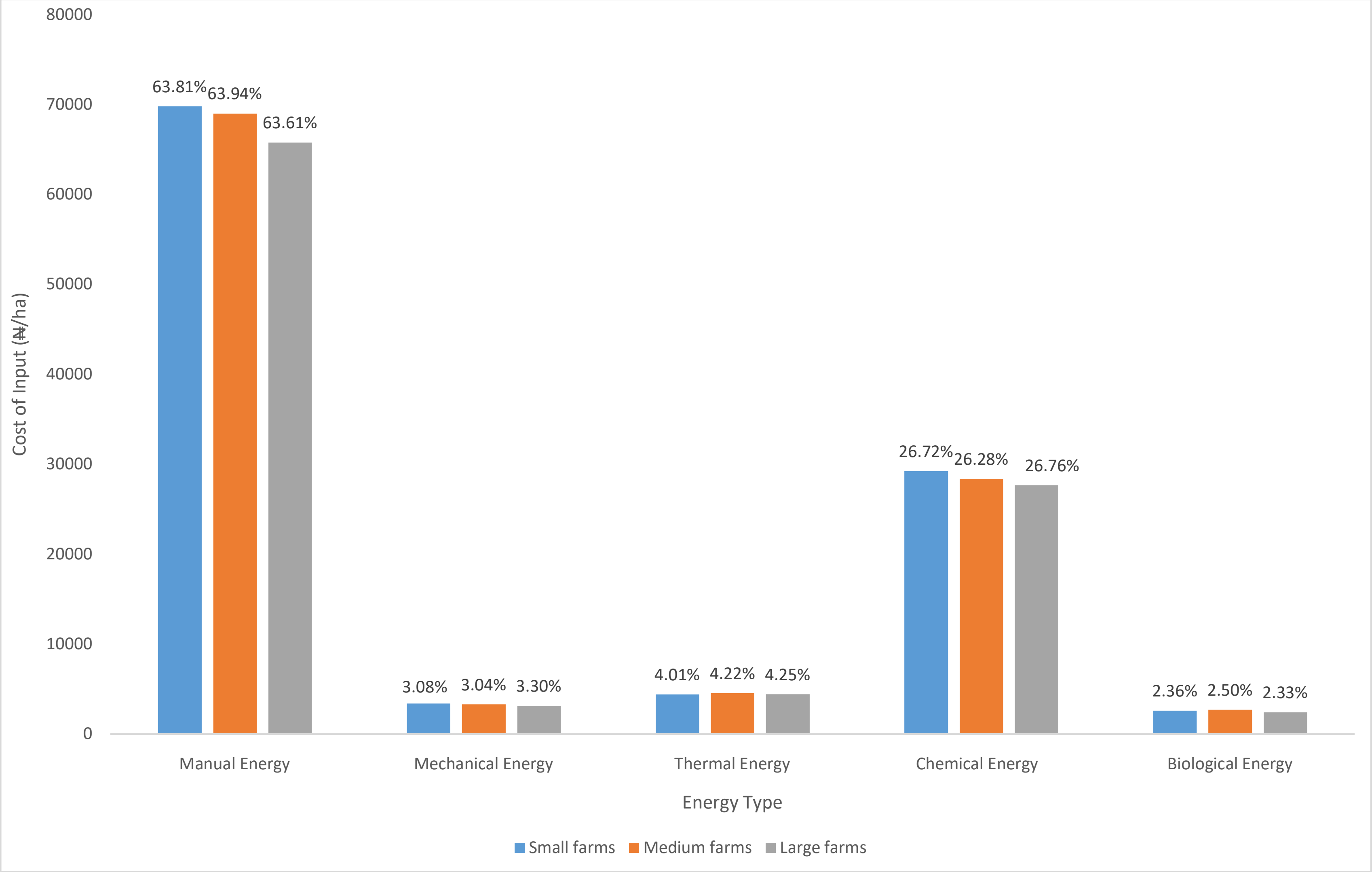

Figure 13: Cost of Energy Patternfor RiceCultivation

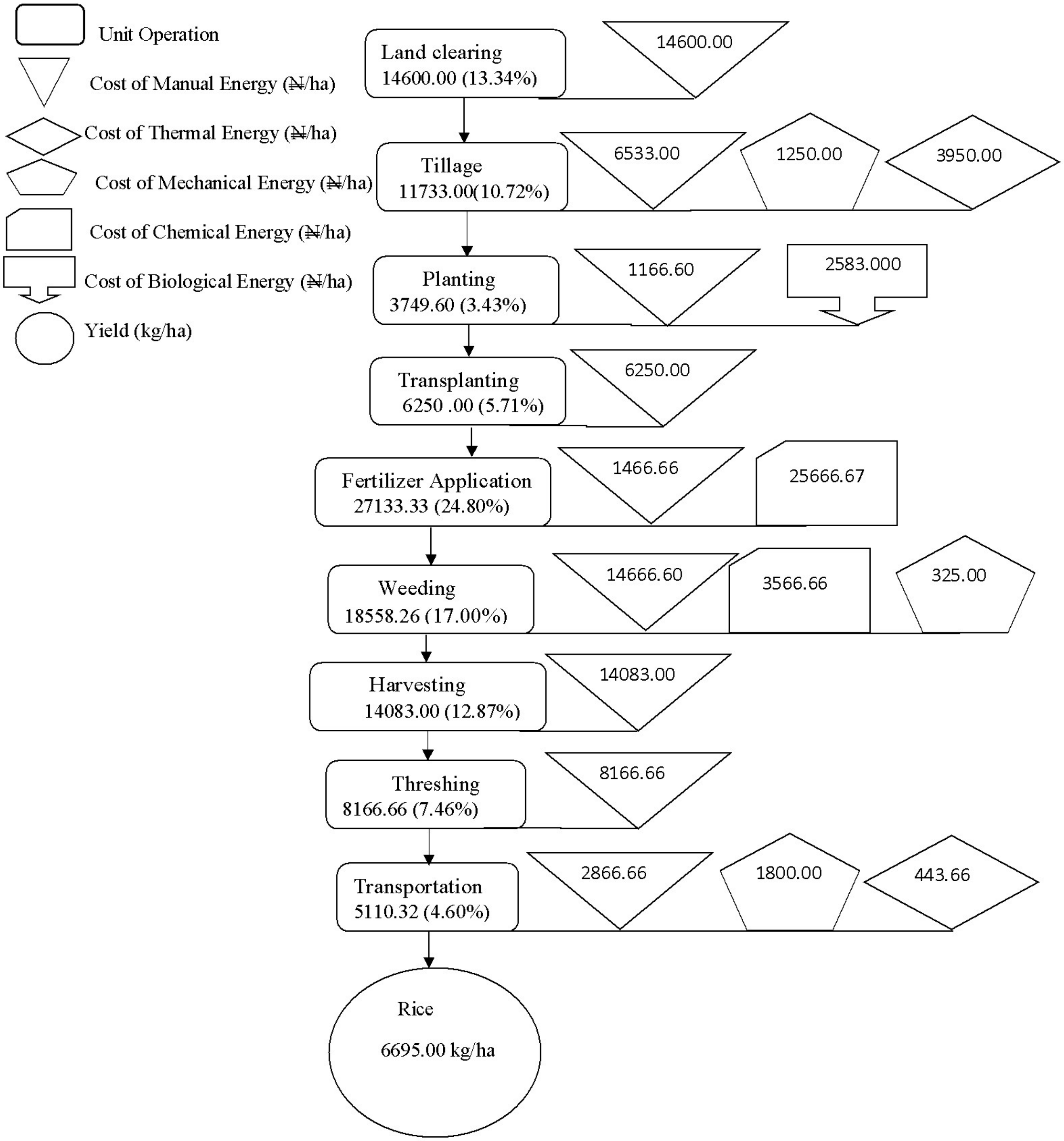

Figure 14: Economic FlowDiagraminaSmall Rice Farm

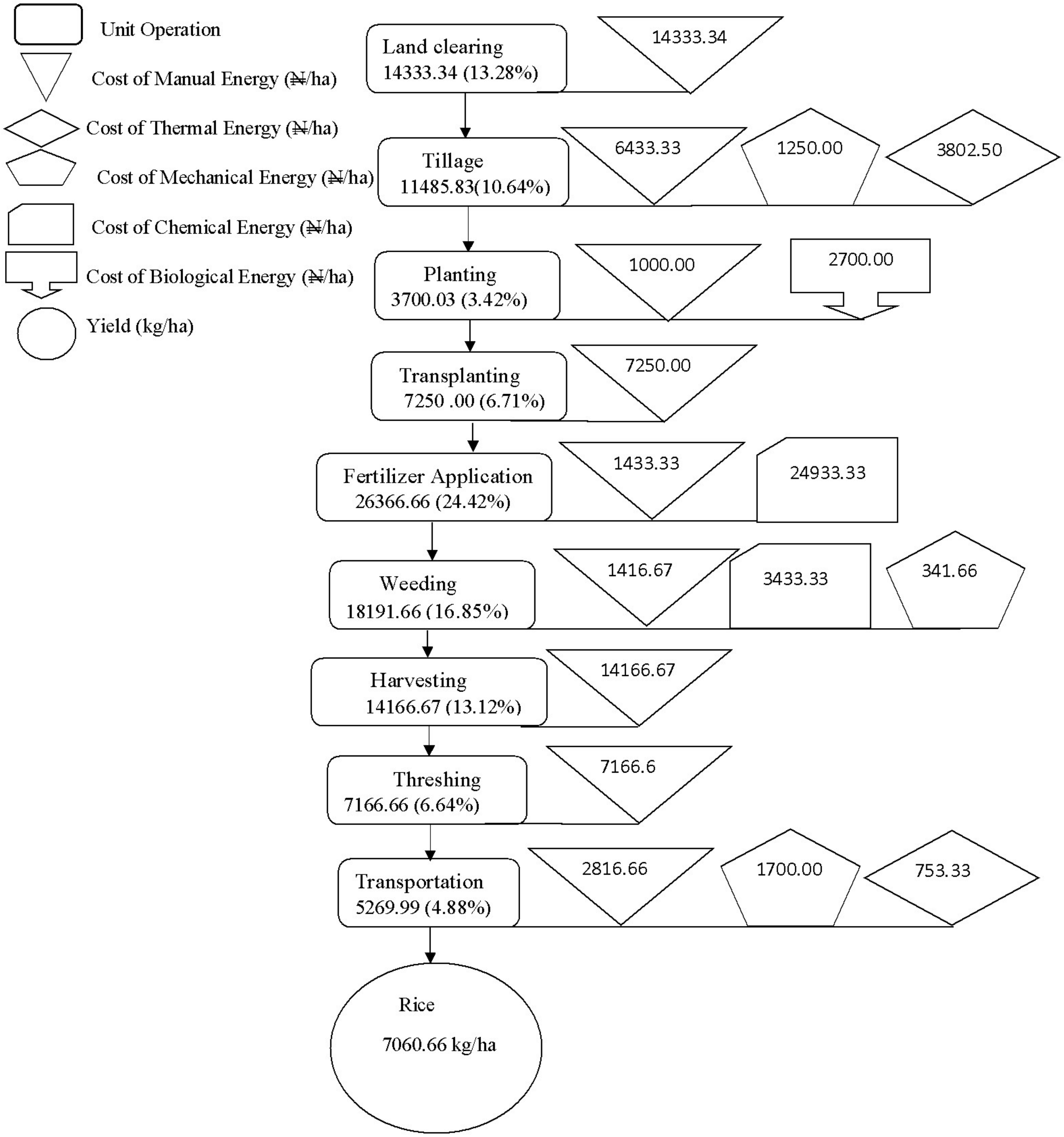

Figure 15: Economic FlowDiagraminaMedium Rice Farm

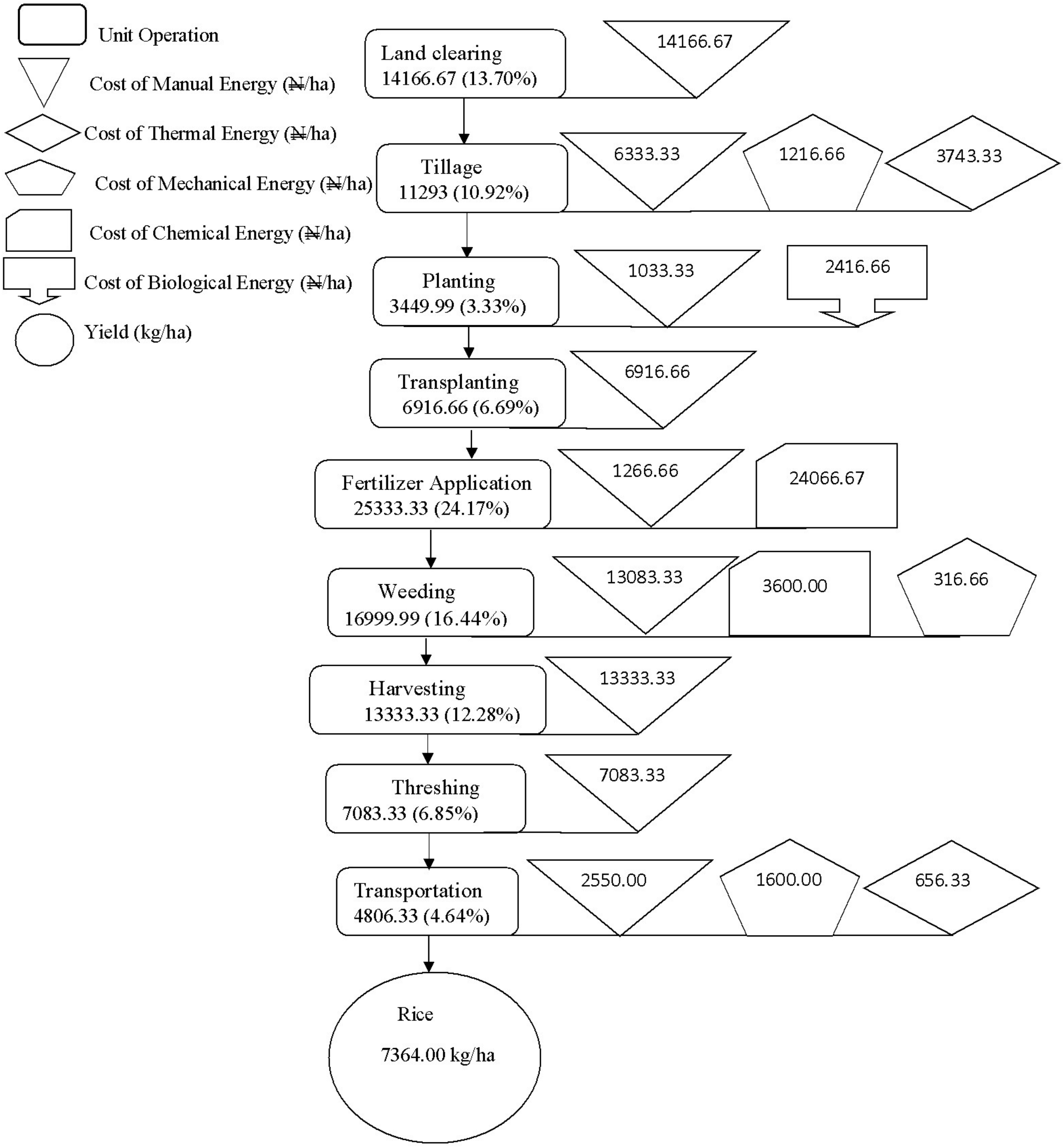

Figure 16: Economic FlowDiagramin a Large Rice

Amount spent on electrical energy in small, medium and large mills were₦294.46, ₦998.46 and ₦974.35 amounting to 2.40, 9.71 and 9.88% ofthetotalinputcost of processing rice in small,mediumandlarge mills, respectively,as shown in Figure 17 was a variation in the amount spent on electrical energy as we move from small to large mills. Small mills has the minimum cost input in electrical energy because some mills use traditional stove (firewood) in parboiling and some mills does de-stone their rice.

Thermal energy cost contributed the least to the total cost of rice processing in the three categories of mills. About ₦2257.32 (18.42%), ₦1080.79 (10.51%) and ₦984.06 (9.98%) were spent in small, medium and large mills, respectively as shown in Figure 17.It decreased from small to large mill. Thedifferences inthermalenergy intensitiesareduetothedifferencesin power sources ofequipment and sophistication of equipmentused.

Generally in all the mills,the highest amount was incurred on rice milling.Insmallmills, amount spent on milling was ₦3290.00 (26%). Amount spent on medium and large rice processing mills were₦3290.00 (29.97%) and₦2984.06 (30.26%), respectively. Thiswas because the mills depended heavily on fuel powered milling machines dueto theepilepticsupplyofelectricityfromthenationalgridinNigeria. The cost of diesel fuel was high, it was sold at ₦160 per liter in Nigeria when this research was conducted.There was a decrease in the cost of milling from small to large mills. This was because of variationsinthe fuel requirementsbythemilling machines during this study which decreases from small to large mills. The decrease can be attributed to ageofthe milling machine andextenttowhich millingmachines capacitywasused.

Also, parboiling operation was the next most capital intensive operation. Amount spent per 1000kg on parboilingin small, medium and large rice mills were ₦3166.66 (25.84%), ₦2322.00 (23.55%) and ₦2338.83 (22.75%), respectively,as shown in Figure 18 to 20.There was a decrease in the cost incurred on this operation from small to large mills. The variation can be attributed to different method of parboiling been adopted by the mills ranging from traditional method in small mills, to semi- mechanized and mechanized method in medium and large farms, respectively.

In small mills,amount spent per 1000kg on drying, sorting and packaging were ₦1500.00 (12.24%), ₦ 1257.08 (10.265%) and ₦ 1029.00 (8.39%), respectively, as shown in Figure 18. Similarly, in medium mills, amount spent per 1000kg on drying, sorting and packaging operations were ₦1169.33 (11.37%),₦1257.08 (12.23%) and ₦ 1029. 25 (10.01%), as shown in Figure 19. Also, in large mills, ₦ 1172.33 (11.89%), 1123.63 (11.39%) and ₦ 1090.56 (11.06%) were spent on these operations as shown in Figure 20.

The least amount was spent on pre- cleaninggenerally in all the mills.Amount spent per 1000kg on small, medium and large mills were ₦ 751.46 (6.13%),₦146.86 (1.39%) and ₦146.86 (1.38), respectively.

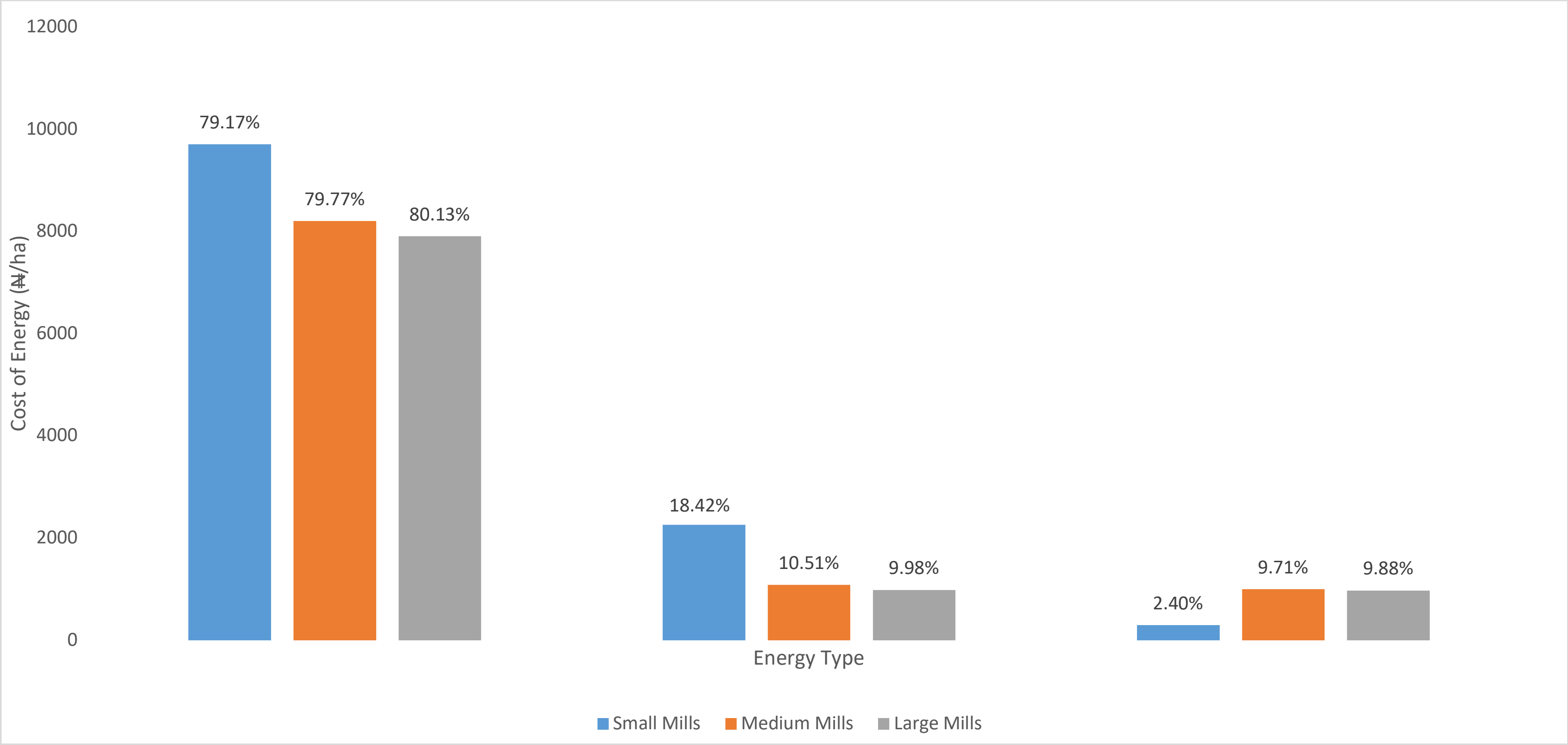

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Figure 17: Cost of Energy Use Pattern for Rice Processing

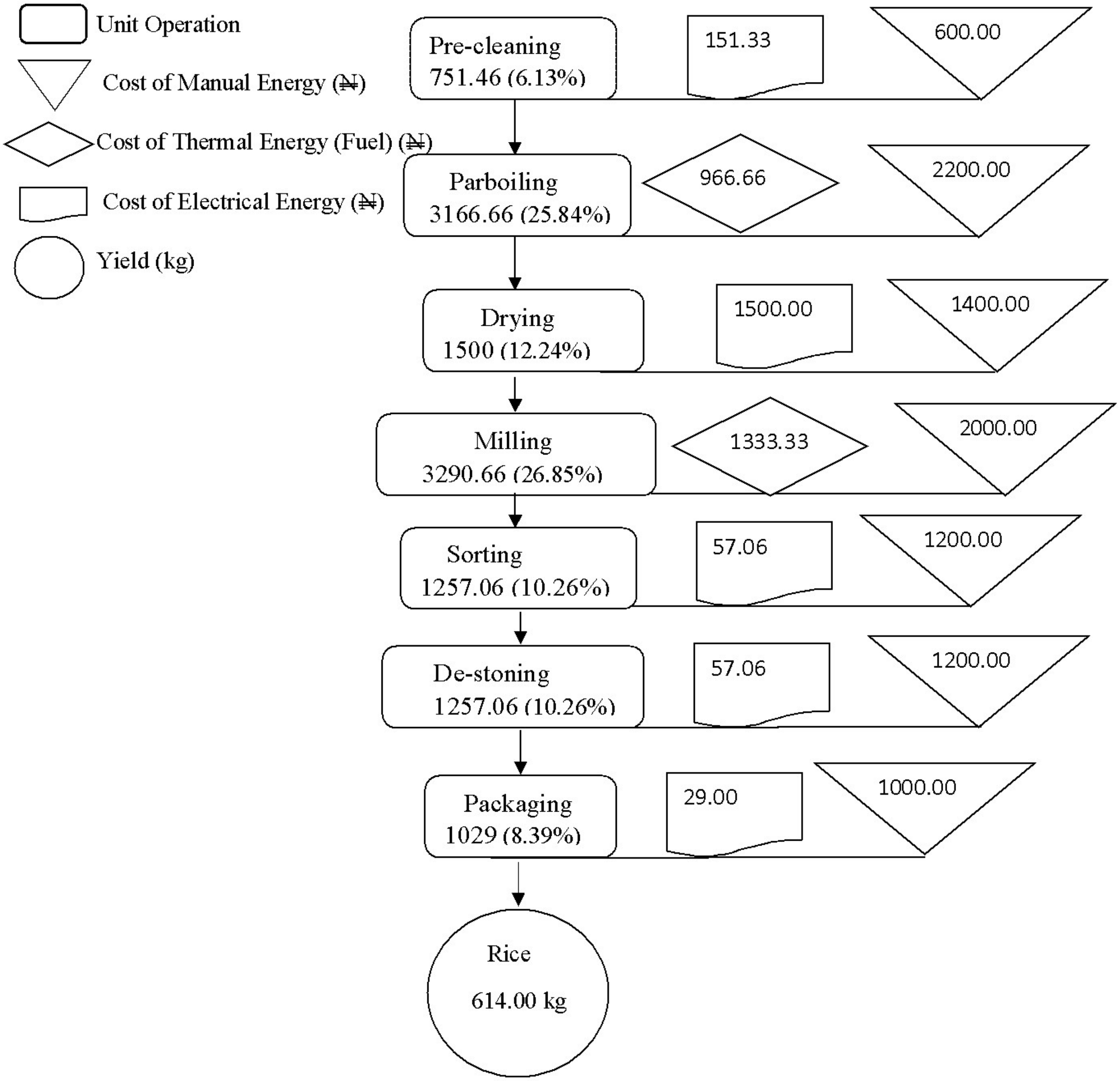


Figure18:EconomicFlowDiagraminaSmall Rice Mill

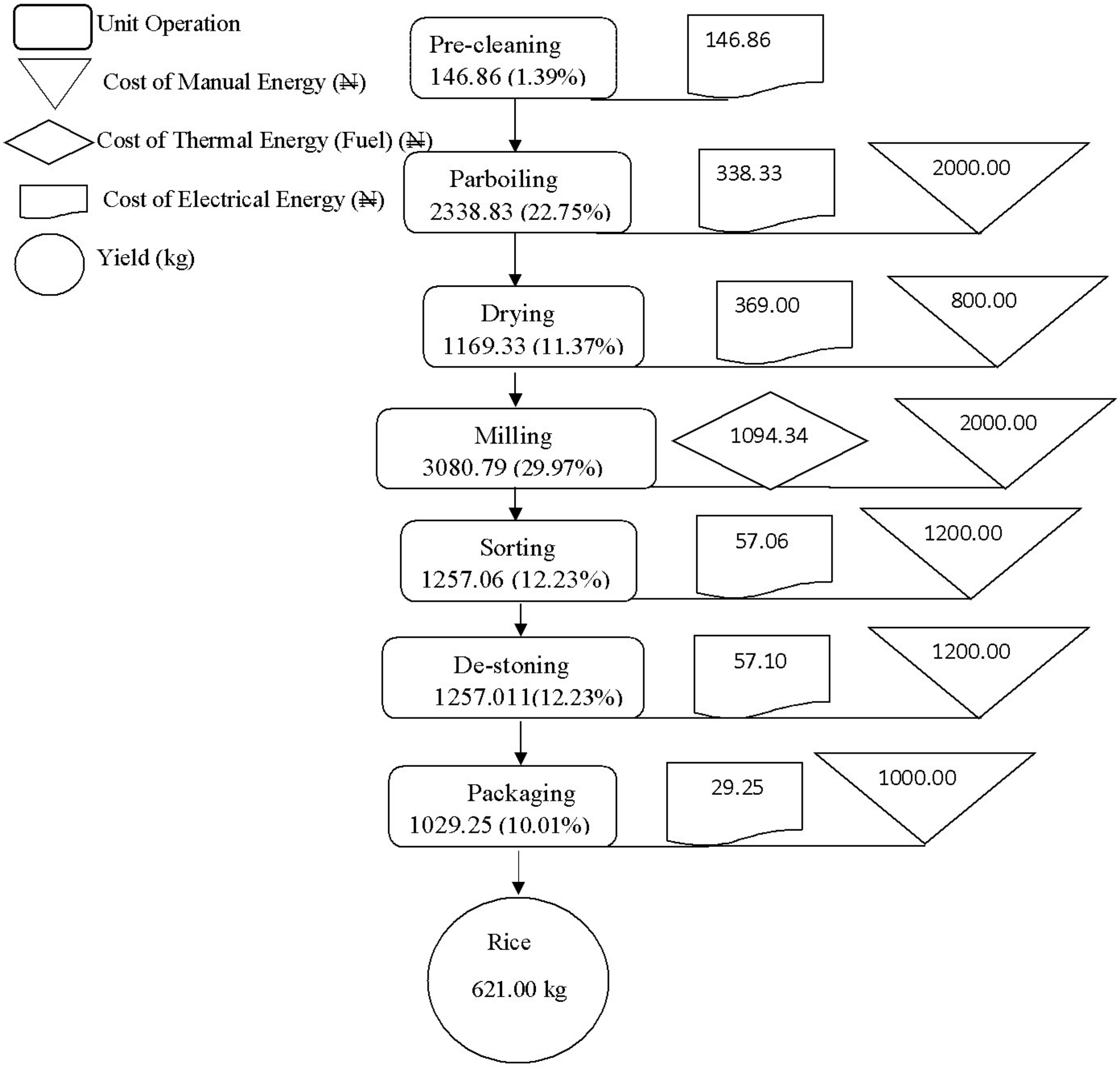


Figure19:EconomicFlowDiagramaMedium Rice Mill

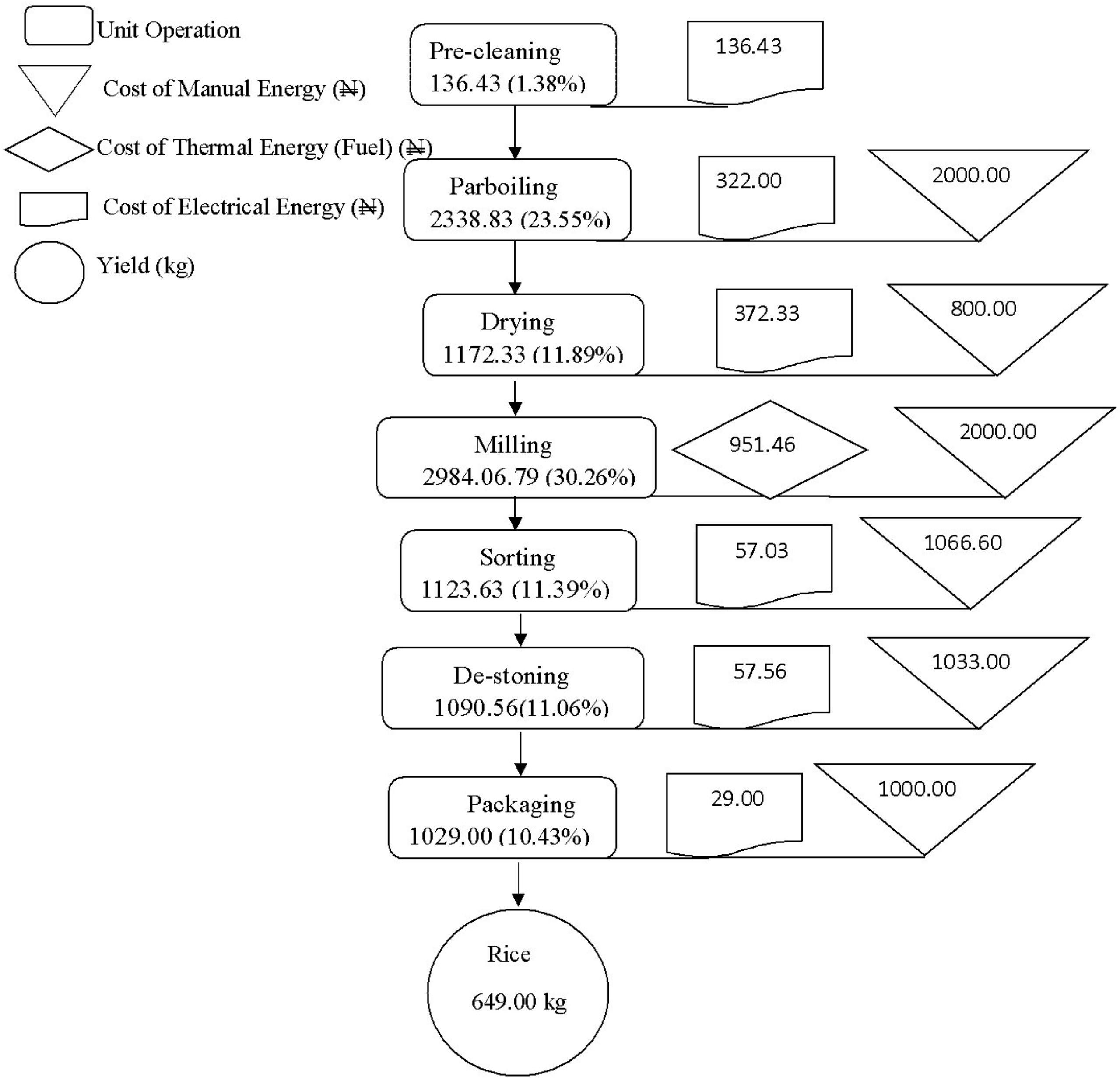


Figure20: Economic Flow Diagram in a Large Rice Mill

4.6.5 Economic indicators for rice Cultivation

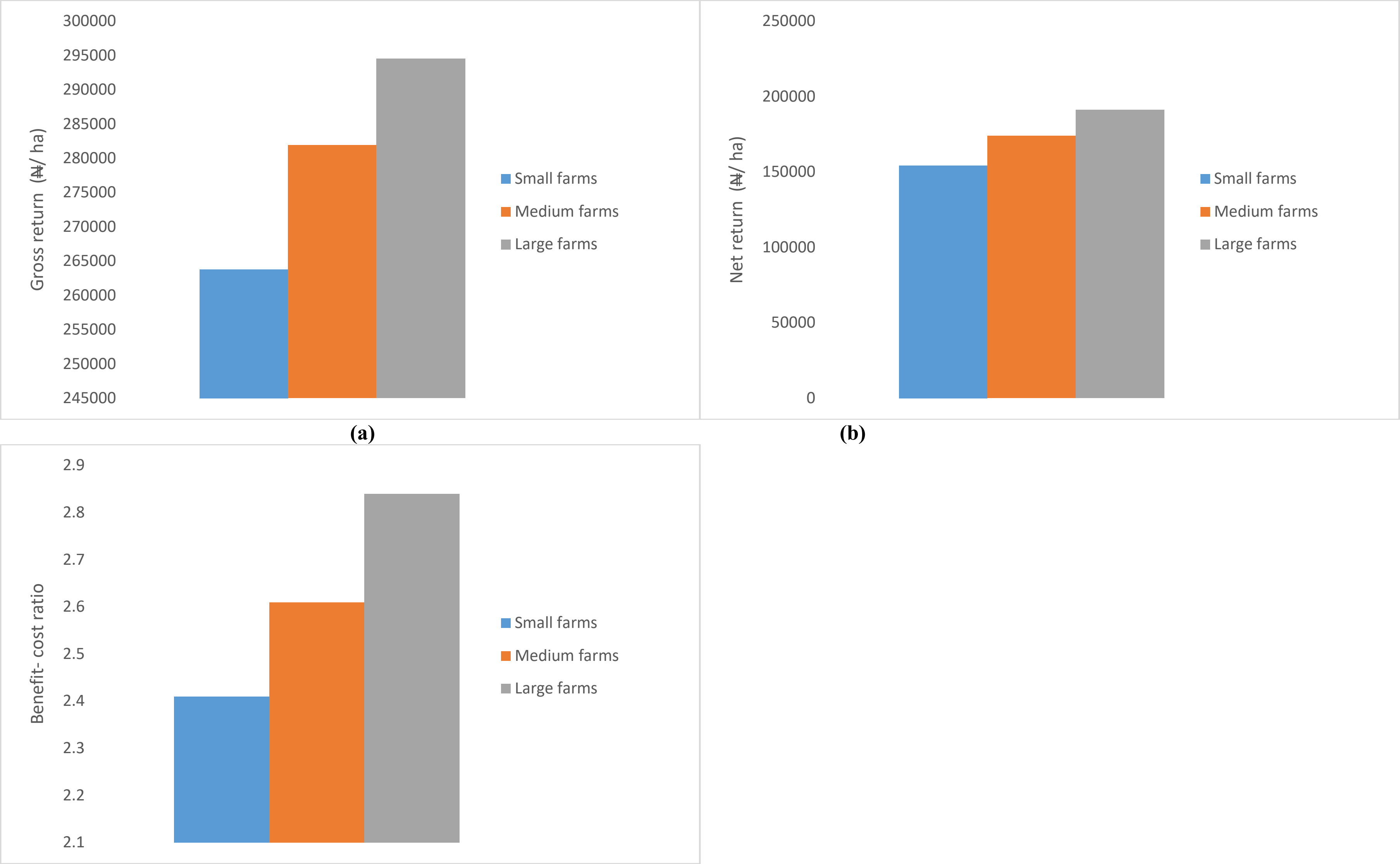
The Gross return obtained for small medium and large farms were ₦263800.00, ₦281926.70 and ₦294559.50, respectively, as shown in Figure 21(a). Thereisan increaseinthegross returnfromsmallfarm tolargefarms. The increase can be attributed to better soil fertility management and crop protection as a result of increasing level of mechanization from small to large farms.

Cost analysis revealed that the net return in rice production per hectare in small, medium and large farms were ₦154414.70, ₦173995.90 and ₦191176.50, respectively, as shown in Figure 21(b).Statistical inference shows that there is significant difference in net return per hectare due increase in scale of production from small to medium and large farms.There was an increase in the net return from small to large farms, indicating that more gain can be obtained in medium and large farms respectively. Benefit-cost ratio in small, medium and large farms were calculated as 2.41, 2.61 and 2.84, respectively, as shown in Figure 21 (c).This indicating that rice production was profitable from economic stand point since the cost-benefit ratio was greater than 1. There was an increase inthecost-benefit ratio fromsmalltolargefarms.Thisindicates that more profit were obtainable in medium and large rice farms, respectively.

4.6.6 Economic indicators for rice processing

The average cost yields for small, medium and large rice mill were ₦153500.00, ₦155250.00 and ₦162287.00, respectively, as shown in Figure 22 (a). The yield increases from small to large mills, indicating that the yield increases as mechanization level increases.

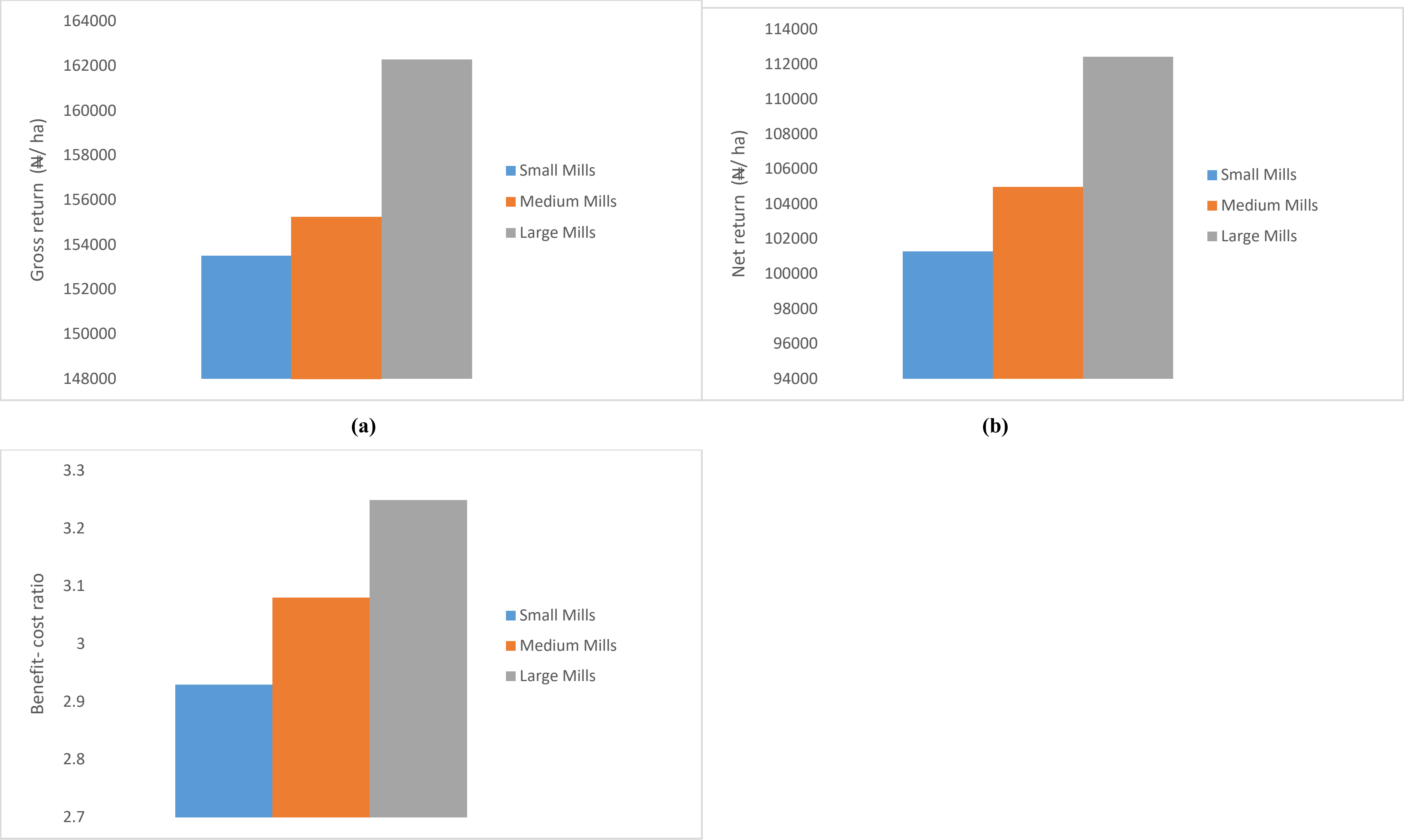
The net return when 1000kg of rice was processed in small, medium and large farmswere ₦ 101284.00, ₦ 104970.00 and ₦ 112427.90, respectively, as shown in Figure 22 (b).Statistical inference shows that there is significant difference in net return per hectare due increase in scale of production from small to medium and large farms.There was an increase in the net return from small to large farms, indicating that more gain can be obtained in medium and large farms respectively. Benefit-cost ratio for small, medium and large mill were 2.93, 3.08, and 3.25, respectively. The cost-benefit ratio greater than 1 indicated that rice processing is profitable from economic stand point. There is an increase inthecost-benefit ratio aswe movefromsmallmilltothelargemills, indicating that the profit obtainable in rice processing increases from small to medium and large mills, respectively. This findings concurs with FAO (2005) and Iheanacho and Mshehia, (2004) report that rice processing is a profitable venture in the North-Central Zone of Nigeria.



(a) **(b)**

(c)

Figure 21: Economic Indicators for Rice Cultivation per Hectare: Gross return (a), Net return (b) and Benefit- cost ratio (c)



(a) **(b)**

(c)

Figure 22: Economic Indicators for Rice Processing:Gross return (a), Net return (b) and Benefit- cost ratio (c)

4.7 Energy Input in Maize Production

4.7.1 Energy input in Maize cultivation

Values of input energy in maize cultivation are presented in Table 22. Energy input in the cultivation of maize varied from 9984.97 to 10086.18 MJ/ha in small farms and it varied from 9832.81 to 10160.25 MJ/ha and 9392.04 to 9480.35MJ/ha in medium and large farms, respectively, as shown in Table 22. There was little variation in the total input energy in maize production per hectare These little variations was because the mode of energy input in all the unit operation were common to all the farms considered .

The average energy input per hectare for small, medium and large categories of farms were 10084.55, 9999.51 and 9445.87 MJ/ha, respectively, as shown by Table 23. There was a decrease in the total energy consumption from small farms to large farms. This shows that more energy was needed on small farms than medium and large farms, respectively. This is an indication of better utilization of energy on medium and large scale farms, respectively. The variation was caused majorly by different amount of biological energy input, mechanical and thermal energy input. It was observed that there is a variation in the quantity of fertilizer utilised in small, medium and large farms, thus the variation in the total energy input. The average energy input per hectare obtained in this study was closer to 9502.17MJ/ha obtained for maize in Nigeria. (Lawal *et al.,* 2014).In a related study, the total energy input in maize cultivation was reported as 11366.2 MJ/ ha (Canakci *et al.,* 2005). Also, Lorzadel *et al,*(2011) reported an average total energy input of 29307.74 MJ/ha in the production of maize in Iran.There was a high variation between the energy inputs obtained in this study compared with the value obtained by Lorzadel *et al.* 2011. The variation was due to high quantity of fertilizer used for maize production in the area of study. Nitrogen fertilizer used in their study had a value of 14299.47 MJ/ha compared to 3923.5, 3959.00 and 3924.33 MJ/ha in small, medium and large farms, respectively, obtained for this study. Mobtaker *et al.*(2012) obtained average energy input of 26917.00 MJ/ha for maize production in kermanshar province of Iran. High value obtained in their study was attributed to high amount of fertilizer used and irrigation water that was considered in their study. The energy input from fertilizer and irrigation water in their study were 15051.00 and 2653.60 MJ/ha, respectively. Also, Shafique *et al.,*(2015) considered three types of tillage systems used for maize production. Energy input obtained when moldboard plough, cultivator and zero tillage was used were 12,387, 11383 and 11301 MJ/ha, respectively. The differences in energy inputs obtained in their study was due to effect of tillage implement on energy output.

Table 22: Energy Input and Output in the Production of Maize (MJ/ ha)

Unit Operation				**Energy Input (MJ/ha)**					
	Small farms			**Medium farms**			**Large farms**		
	Farm 1	**Farm 2**	**Farm 3**	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 1**	**Farm 2**	**Farm 3**
Land clearing									
Manual energy	0.73	0.78	0.76	0.66	0.67	0.77	0.63	0.62	0.61
Mechanical energy	173.00	175.20	179.50	163.03	163.00	160.00	152.00	152.00	152.00
Thermal energy	1450.50	1489.40	1449.10	1125.60	1156.20	1308.70	1081.00	1099.00	1086.00
Tillage									
Manual energy	0.67	0.63	0.68	0.67	0.78	0.71	0.65	0.64	0.66
Mechanical energy	165.00	162.20	161.0	162.03	160.50	162.50	162.00	161.5	163.03
Thermal energy	1410.40	1401.60	1485.60	1197.20	1247.20	1261.00	1044.0	1075.5	1078.50
Planting									
Manual energy	16.70	16.75	17.05	0.70	0.75	0.77	0.70	0.81	0.73
Mechanical energy	-	-	-	159.75	167.00	162.50	149.50	146.70	143.00
Thermal energy	-	-	-	265.40	263.90	263.50	260.00	263.6	262.00
Biological energy	386.50	382.30	386.00	396.80	383.00	352.80	355.80	358.00	348.50
Fertilizer application									
Manual energy	11.65	11.81	11.63	10.89	10.13	10.80	10.68	10.76	10.85
Chemical energy N	3958.50	3948.50	3963.50	3982.00	3918.00	3977.00	3607.5	3613.5	3652.00
P_2O_5	351.00	354.00	344.50	352.00	348.50	359.50	345.0	350.0	343.50
K_2O	283.00	284.00	274.00	234.50	273.00	285.00	232.5	233.0	235.00
Weeding									
Manual energy	5.21	5.36	5.81	0.63	0.66	0.66	0.66	0.68	0.65
Chemical energy (Herbicide)	396.00	392.50	392.50	392.00	375.00	395.00	362.0	371.00	354.00
Mechanical energy	392.05	394.37	392.30	287.28	287.37	288.00	275.28	273.97	274.00
Thermal energy	-	-	-	71.175	73.92	73.44	68.22	70.23	70.05
Harvesting									
Manual energy	32.00	32.04	32.01	30.24	31.81	29.35	31.0-	30.20	30.92
Threshing									
Manual energy	2.76	2.84	2.76	2.78	2.78	2.76	2.80	2.65	2.71
Mechanical energy	154.27	159.75	150.04	129.45	136.58	131.95	127.22	129.00	123.18
Thermal energy	388.4	387.20	384.60	336.5	336.78	336.70	338.40	337.90	338.00
Transportation									
Manual energy	2.63	2.65	2.63	2.85	2.835	3.07	3.50	3.59	3.55
Thermal energy	343.00	353.00	349.00	439.00	442.45	443.77	568.0	577.00	578.00
Mechanical energy	129.40	129.30	129.0.0	147.80	150.00	150.00	213.0	218.50	214.00
Energy Input (MJ/ha)	10053.37	10086.18	9984.97	9890.93	9932.81	10160.25	9392.04	9480.35	9445.44
Yield (Kg/ha)	2730.00	2750.00	2900.00	3405.00	3363.00	3347.00	3335.00	3513.00	3357.00
Energy Output (MJ/ha)	40131.00	40425.00	42630.00	50053.50	49436.10	49200.90	49024.000	51641.10	49347.90

Table 23: Average Energy Input and Output in the Production of Maize (MJ/ ha)

Energy Input (MJ/ ha) Unit Operation	Small farms	Medium farms	Large farms
Land clearing			
Manual energy	0.75	0.70	0.62
Mechanical energy	175.90	162.01	152.0
Thermal energy	1463.00	1196.83	1088.67
Tillage			
Manual energy	0.66	0.72	0.65
Mechanical energy	162.73	161.67	162.17
Thermal energy	1432.53	1235.13	1066
Planting			
Manual energy	16.83	0.74	0.74
Mechanicalenergy	-	163.08	146.4
Thermal energy	-	264.26	261.86
Biological energy	384.93	382.48	354.10
Fertilizer application			
Manual energy	11.69	10.60	10.76
Chemical energy N	3956.83	3959	3624.33
P_2O_5	349.83	353.33	346.16
K_2O	280.33	264.16	233.50
Weeding			
Manual energy	5.46	0.65	0.66
Chemical energy (Herbicide)	393.66	387.33	362.33
Mechanical energy	392.9	287.55	274.41
Thermal energy	-	72.72	69.5
Harvesting			
Manual energy	32.01	30.46	30.7
Threshing			
Manual energy	2.78	2.77	2.72
Mechanical energy	154.68	132.66	126.46
Thermal energy	386.73	336.66	338.1
Transportation			
Manual energy	2.64	2.91	3.54
Thermal energy	348.33	441.74	574.33
Mechanical energy	129.35	149.26	215.16
Energy Input (MJ/ha)	10084.55	9999.51	9445.94
Yield (kg/ha)	2793.33	3371.66	3401.66
Energy Output (MJ/ha)	41062.00	49563.50	50004.34

4.7.2 Energy Use Pattern in Maize Cultivation

The pattern of energy use as shown in Figure 23 revealed that chemical energy was the most used energy resourcesgenerally inallthefarms. Chemical energy were 4980.65, 4963.83 and 4566.32MJ/ha which accounted for 49.38, 49.64 and 48.34% of the total input energy in small, medium and large farms, respectively.Therewerenoticeablevariationsinthe chemical energy requirements by the farmsduringthestudy.Thisvariationwas duetolackof adequateattentionor lackof concernfor energyconservation.High chemical energy usage in this study was due to high quantity of fertiliser. The average use of fertilizer was 150kg/ha in the maize production. The result obtained in this study agrees with the findings of Lorzadeh *et al.* (2011) and Mobtaker *et al.* (2010) for maize production. Also, this result validates the findings of Hematian *et al*. (2012), who reported that chemical fertilizer had the biggest share (56% approximately) of total energy inputs in maize production.

The contributions of thermal energy fromthetotal energy in small, medium and large farms were 36.00% (3630.59 MJ/ha), 35.47%(3547.34 MJ/ha) and 35.98% (3398.46 MJ/ha), respectively,as shown in Table 31.High thermal energy input implies that there is a measure of mechanization in the production of maize in all the farms. The differences in thermal energy intensities are due to the differences level of mechanization, size of the farms and sophistication of equipment used.

In small farms, the contribution of mechanical and biological energy were 10.4% (1015.56 MJ/ha) and 0.78% (384.93 MJ/ha), respectively. Mechanical and biological energy in medium farms were 10.56% (1056.23MJ/ha) and 3.82% (382.48 MJ/ha), respectively. Their contributions in large farms were 11.39% (1076 MJ/ha) and 3.75% (354.1 MJ/ha), respectively. It was observed that mechanical energy increased from small to large farms, indicating that mechanization increased from small to large farms.

Manual energy was the least energy input in all the farms. It contributed 0.72% (72.82MJ/ha), 0.49% (49.55MJ/ha) and 0.53% (50.39 MJ/ha) in small, medium and large farms, respectively.Lorzadeh *et al*.,(2011)reported that the lowest share of total energy used in maize production was manual energy (0.57%) which is a renewable resource of energy.Similar results are reported by researchers which showed that energy input of human labour has little part of the total energy input in agricultural crops production (Sartori *et al.,* 2005; Strapatsa *et al.,* 2006; Kizilaslan, 2009).

The contributions of indirect energy (biological, chemical, mechanical)in small, medium and large farmswere 63.14% (6381.14 MJ/ha), 64.02% (6402.53 MJ/ha) and 63.47% (5997.20MJ/ha), respectively, as shown in Figure 24 energy (manual, thermal)in small, medium and large farms were36.86% (3703.41 MJ/ha), 35.98% (3596.86 MJ/ha), 36.53% (3448.67 MJ/ha), respectively. The contributions of indirect energy was more than that of direct energy.The higher ratio of indirect over direct energy is in agreement with the findings of Mohammedshirazi *et al.* (2012) for maize production. In a similar study,55.35% of the total energy input use in maize production was indirect energy, while 35.58% was direct energy(Mohadeseh, 2016).

The contributions of renewable energyin small, medium and large farms were 4.53, 4.31 and 4.27% of the total energy input, respectively. While non-renewable were 95.47, 95.69 and 95.73%, respectively.These results showed that maize production in the study area is mainly depended on indirect energy form dominated by biological, chemicals, and mechanical energy. The proportion of non-renewable energy used in the surveyed maize farms was higher than the renewable energy form. This implies that maize production in the study area depend heavily on fossil fuel which in the long run, may lead to environmental problems such as land and water pollution. This similar to what was obtained by Mohadeseh, (2016). The renewable sources represent an effective alternative to fossil thermals for preventing resources depletion and for reducing pollution (Cosmi, 2003).

Considering theunitoperationsduringproduction(Figures25to27),fertilizer applicationwasthe most energy intensive operationinallthefarms. In smallfarms, fertilizer applicationaccounted for45.60 % (4598.68 MJ/ha) ofthetotalinputenergy. While, it accounted for 45.87% (4587.10 MJ/ha) and 44.62% (4214.75 MJ/ha)of the total energy in medium and large farms, respectively.Therewas adecreaseinthe energy consumed in fertilizer application by the farms from small to large farms. The decline in energy consumption as we move from small to large farms show better energy utilization in medium and large farms, which may be due energy conservation practice. Thisclearlysupported the previous findings that chemical energy (fertilizer) input was the most used input resources in all the three farms.

Land clearing were 1639.65, 1359.54 and 1241.29 MJ/ha in small, medium and large farms, respectively. This accounted for 16.25, 13.60 and 13.14% of the total energy input in small, medium and large farms, respectively. Tillage were 1595.92, 1397.53 and 1228.82 MJ/ha which accounted for 15.82, 13.98 and 13.09% of the total energy in small, medium and large farms, respectively. High energy input for these operation were attributed to lack of energy conservation. These variation may be due to different tillage system adopted and level of sophistication of equipment. Effort should be made at decreasing the energy input in tillage and land clearing operation in maize production in Nigeria.

In the small farms, planting accounted for 3.98% (401.76 MJ/ha) of the total input energy. About 8.11% (810.56) MJ/ha was consumed by planting operation in the medium farms, while, 8.07% (763.1 MJ/ha) was consumed in the large farms. Planting was done manually in small farms. While, it was done mechanically in medium and large farms as shown in the Figures 25 and 27. This contributed to the variation in all the farm categories.

As shown in Figure 25, weeding, threshing and transportation accounted for 7.85% (792.02 MJ/ha), 5.39% (544.19 MJ/ha)and4.76% (480.32 MJ/ha) in small farms, respectively. In medium farms, weeding, transportation and threshingaccounted for 7.48% (748.25 MJ/ha), 5.94% (593.92MJ/ha)and 4.72%

(472.09MJ/ha), respectively, as shown in Figure 26.Transportation, weeding and threshingaccounted for 8.39%(793.03MJ/ha), 7.48% (706.9 MJ/ha) and 4.94% (467.28 MJ/ha), respectivelyin large farms,as shown in Figure 27. There was little noticeable variations in the energy requirements for weeding, transportation and threshing generally in all the farms. This was because the operations were done using similar methods. However, there was anincreaseinenergy input for transportation from small to large farms. This trend show that the amount of thermal energy used for this operation increases from small to large farms. This was because the distance the vehicle as to cover to get to the farms increases from small to large farms.

Itwasobservedthatinallthefarms,harvesting has the least energy input.It accounted for 0.31% (32.01MJ/ha), 0.30% (30.34 MJ/ha) and 0.32% (30.70 MJ/ha) of the total energy in small, medium and large farms, respectively. Harvesting was done manuallyin all the farm.

4.7.3 Energy Output in MaizeCultivation

The average yields of maize in small, medium and large farms were 2793.33, 3371.66 and 3401.66 kg/ha, respectively, as shown in Table 23. There was an increase in the yield obtained from small to large farms, indicating that more yield is obtainable in medium and large farms, respectively.Nyaudoh, (2010) considered four types of tillage systems used for maize production. The average maize yield reported for conventional, minimum, traditional and zero tillage were 2640, 3140, 3150 and 2650 kg, respectively. Shaftique *et al.*'s finding were 4380.0, 3972.0 and 3136.0kg/ha for moldboard plough, cultivator and zero tillage, respectively. The variations in values obtained by Nyaudoh, (2010) and Shaftique *et al.*(2015) can be attributed to effect of different tillage system used.Maize grain yields in Nigeria varied from 800 kg/ha to 8000 kg/ha depending on variety used, ecology, farming system adopted and management practices involved (Olakojo and Olaoye, 2007).

The output energy for maize production in small, medium, and large farms were 41062.00, 49563.50, 50004.34 MJ/ha, respectively, as shown in Table 23. This is closer to 54639.90 obtain in Kermanshah province of Iran from maize (Hematian *et al.*, 2012).

4.7.4 Energy indicatorsfor Maize cultivation

4.7.4.1 The Net Energy

The net energy values for maize cultivation in small, medium and large farms were 30977.45, 39563.99 and 40558.4 MJ/ha, respectively as shown in Figure 28 (a). The net energy value increased from small to large farms, indicating that more energy was gained in medium and large farms than in small farms.

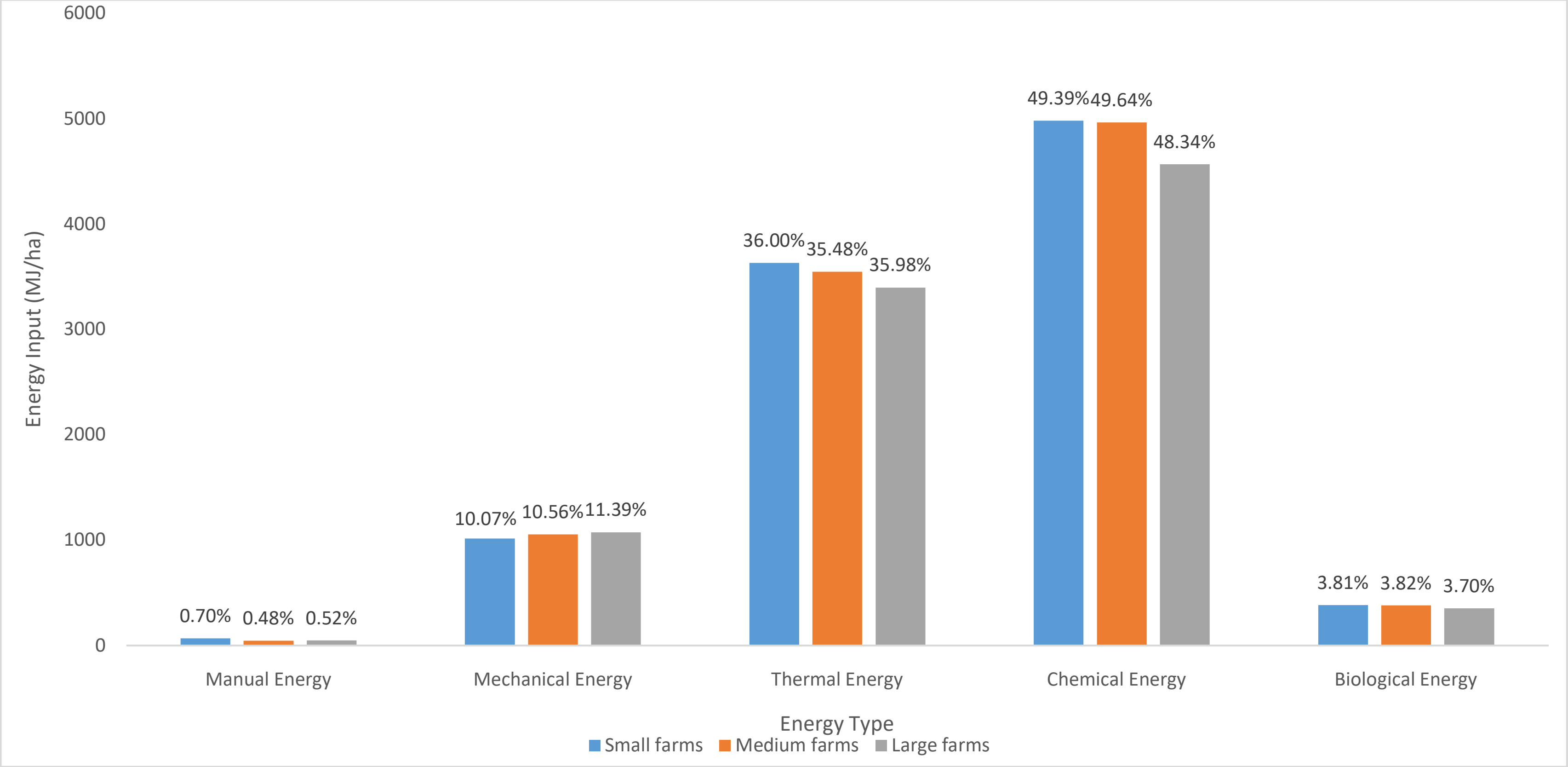


Figure 23: Energy use Pattern for Maize Cultivation

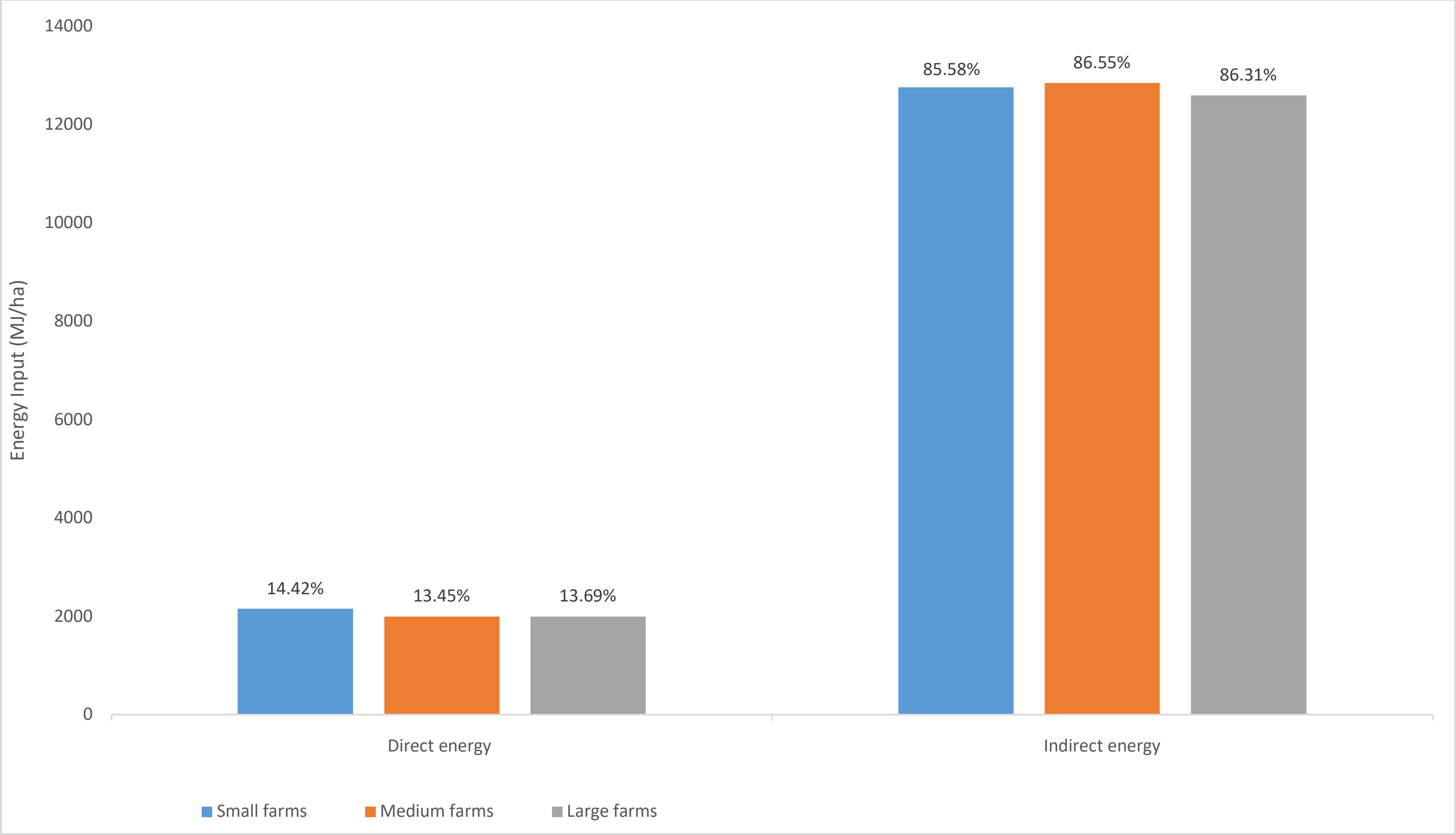


Figure 24: Distribution of Energy Forms in Maize production

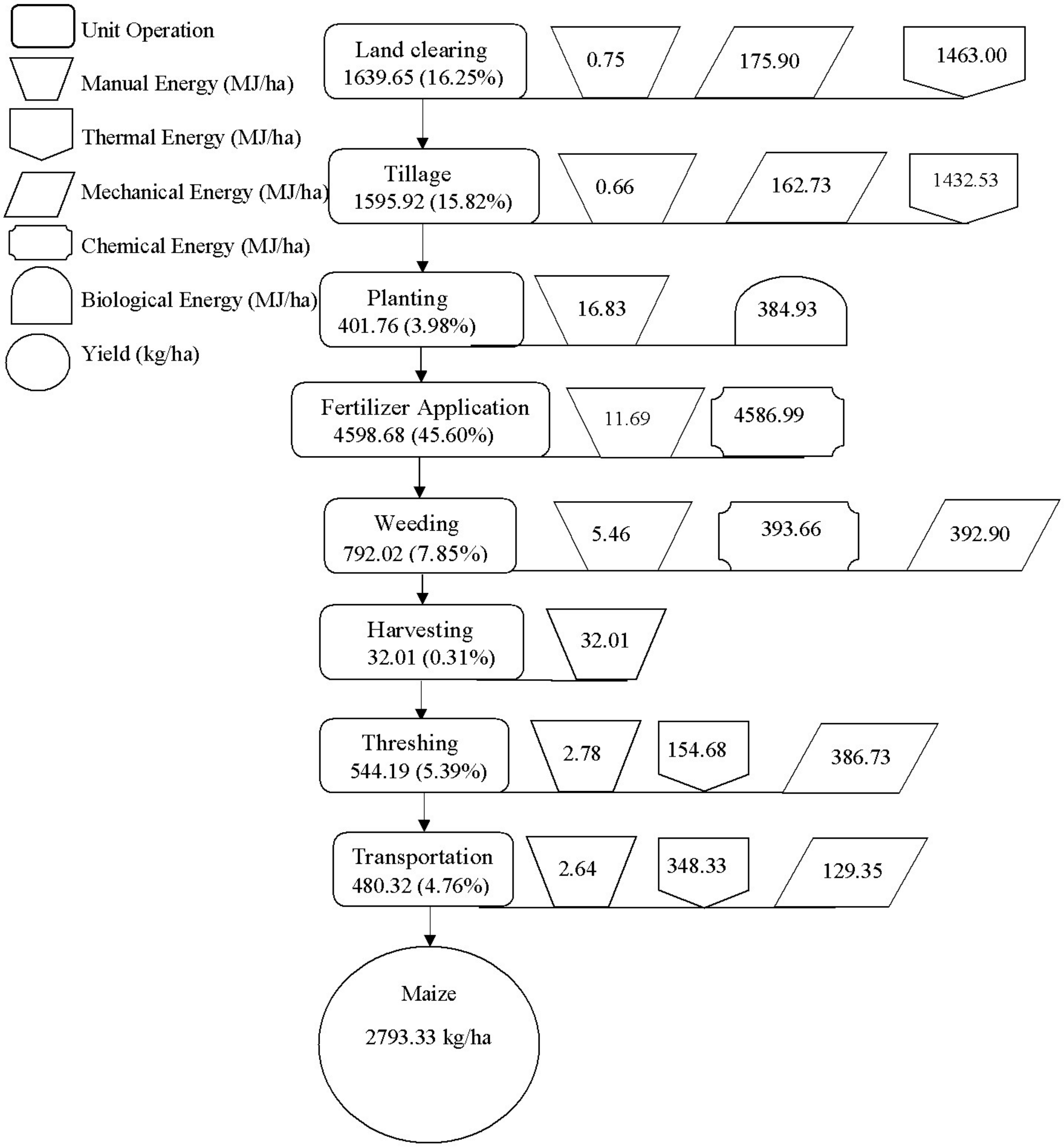


Figure 25:EnergyFlowDiagraminaSmall Maize Farm

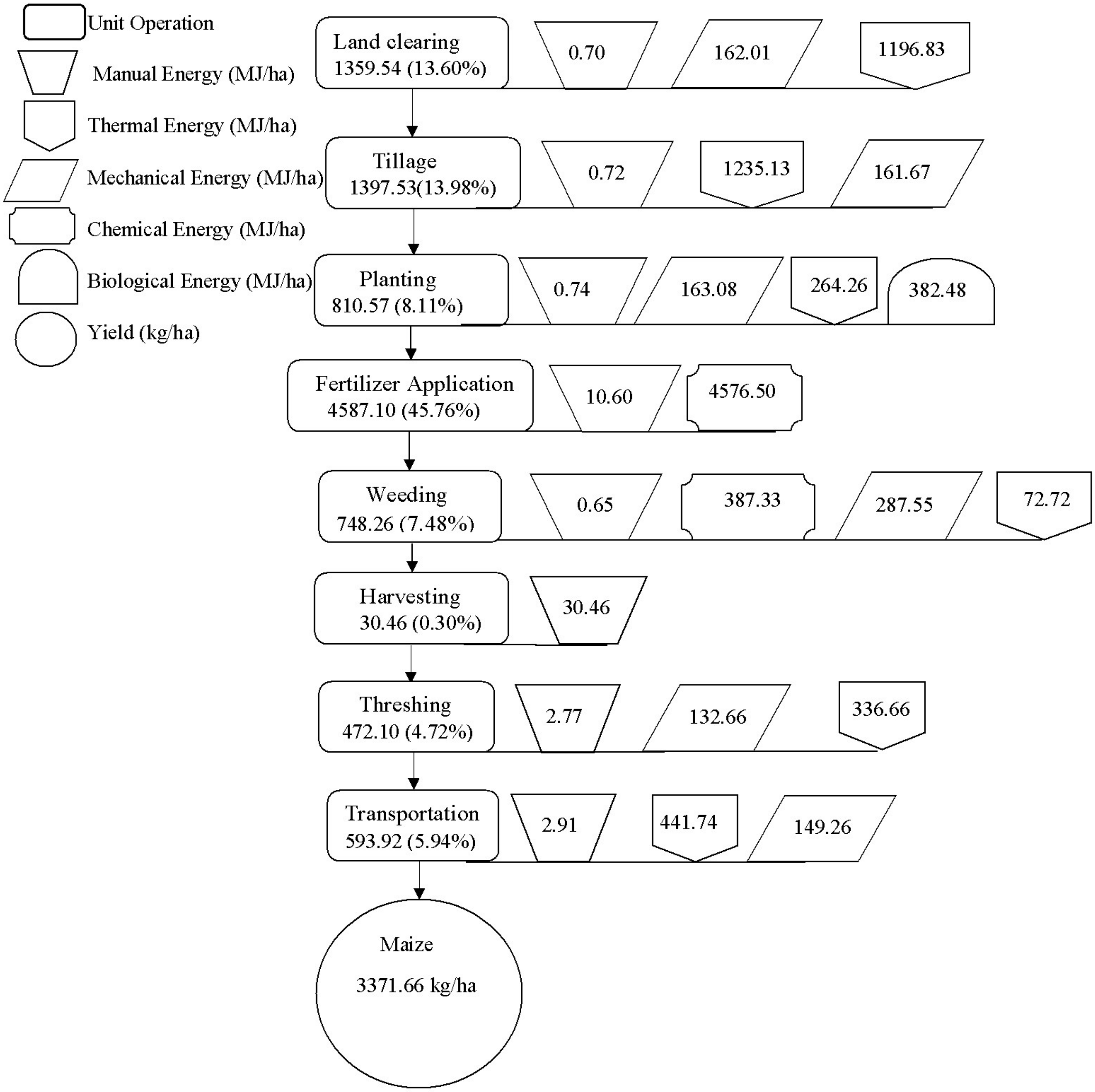


Figure 26:EnergyFlowDiagraminaMedium Maize Farm

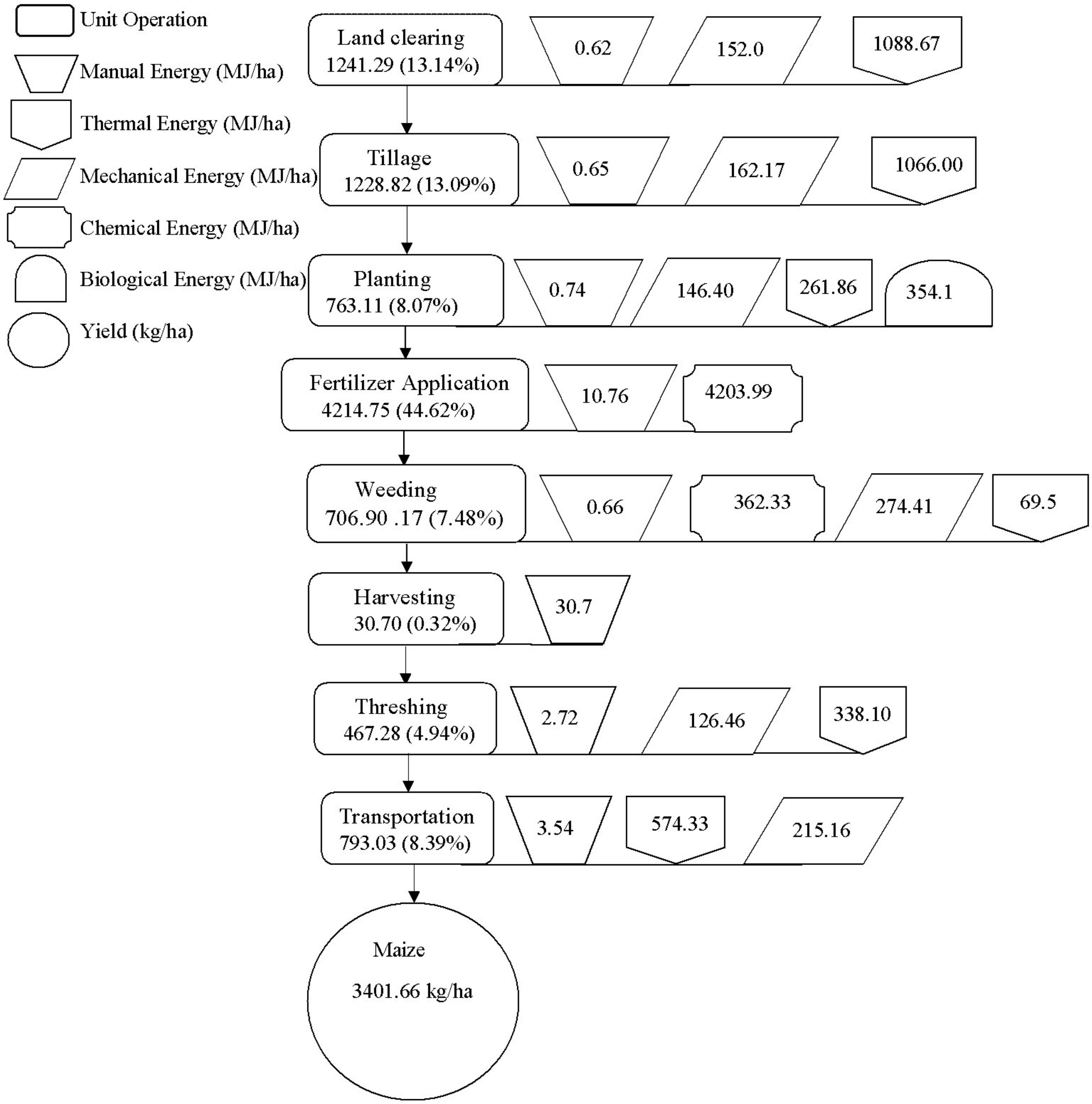


Figure 27:EnergyFlowDiagraminaLarge Maize Farm

The net energy values for maize cultivation in this study was lower than53972.00MJ/ha obtained by Chamsing, *et al*. (2006) in Thailand. Higher net energy value in Thailand was as a result of higher yield of maize 4532.33 (kg/ha) as compared to what was obtained from this study.

4.7.4.2 The Energy Productivity

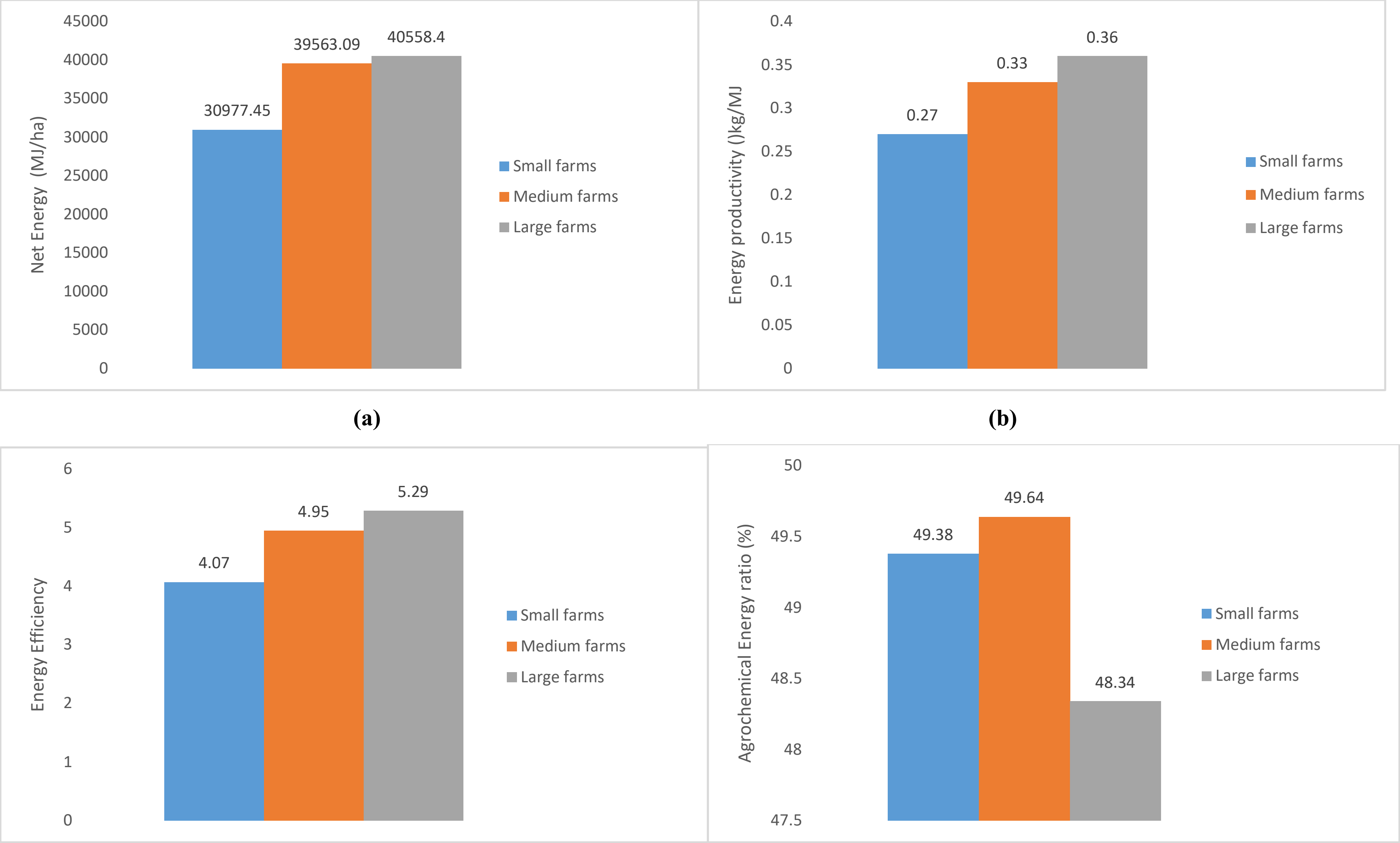
Energy productivity in small, medium and large farms were 0.27, 0.33 and 0.36 kg/MJ, respectively as showing in Figure 18 (b). These indicated that 0.27, 0.33 and 0.36 kg of maize were produced when 1 MJ of energy was applied to small, medium and large farm, respectively.There was an increased energy productivity from small to large farms, indicating that more kilograms of maize were produced per unit energy (1MJ) input in medium and large farms.Pishgar *et al.* (2011) reported that in corn silage production, energy productivity was 0.28 kg/ MJ. Also, Abdi *et al.* (2012) reported energy productivity value of 0.20 kg/MJ for maize productionSystem inKermanshah Province of Iran.The value less than the values obtained for this studies indicated that more energy was utilised in the production of maize in their study compared to this study.

4.7.4.3 The Energy Efficiency

The energy efficiencies for maize production in small, medium and large farms were 4.07, 4.95 and 5.29, respectively, as shown in Figure 28 (c). These indicated that energy were efficiently utilised in all the farms.There was increase in energy efficiency from small to large farms, indicating that more energy was used for maize production in small than in medium and large farms. The energy efficiencies were closer to 5.03 obtained by Ozpinar *et al.*(2015) in West Turkey. The higher energy ratiosin this study was attributed to higher yield of maize. The lowest energy use ratio value was 4.07 obtained for small farms which indicated low efficient level of energy usage. This could be attributed to the manual energy used by the farmers for some operations in this category which was laborious and time consuming, a scenario similar to the findings of (Singh *et al.,* 1997; Ozkan *et al.,* 2004; Alam *et al.,* 2005; Tolga *et al.,* 2009) who conducted similar work for different types of crops in different parts of the world.

4.7.4.1 Agrochemical energy ratio

Agrochemical energy ratios of maize production in the agro-ecosystems for the respective categories as shown in Figure 28 (d) were 49.39, 49.64 and 48.34%, indicatingthat moreenergy was consumed per fertilizer and chemical inputs production. The agrochemical ratios obtained were similar to what was obtained by lorzdah *et al*.(2011) in Shooshtar, Iran.



(a) **(b)**

(c) **(d)**

Figure 28: Energy Indicators in Maize Cultivation: Net Energy (a), Energy Productivity, (b) Energy efficiency (c) and Agrochemical ratio (d)

4.8 Econometric Model Estimate of Maize Production

The result of the interaction among the input energy as it affected the energy output for maize cultivation is as shown in Table 24 and represented by Equation 72. From the equation, the coefficient of determination was 0.98, indicating that all the different energy inputs contributed immensely to the energy output. The variability in the energy inputs could be explained by this model up to 98%. From Table 24, Durbin-Watson value was 2.10, indicating that the model developed was capable of predicting energy output at different energy inputs beyond the two seasons considered in this work. It means that the equation is valid beyond two seasons.

The results revealed that the impact of manual, thermal, mechanical and biological energy were significant ($p<0.05$).However, the impacts of chemical energies (Nitrogen, phosphorus, potassium, and herbicide) on energy output were insignificant ($p>0.05$), indicating change in these inputs will not have any significant effect on the output.

Mechanical energy and manual energy input had the highest elasticity on output.The coefficients for mechanical and manual energy were 6.72 and 0.60, respectively,as shown in Equation 72. These means that increase in mechanical and manual energy input by 1% would result to 6.72% and 0.60% increase in output energy, respectively.Therefore additional use of machinery per unit area, and increasing mechanization level, would result more yield.This result showed the importance of the role of the machinery in maize production.This is similar to the finding of Mobtaker *et al.*(2012). They reported that human labour and machinery energy with elasticity of 0.42 and 0.40, respectively,were found as the most important variables which influence energy output in maize production.The coefficients of chemical energy phosphorus, fertilizer potassium fertilizerand herbicide were 0.17, 0.12 and 0.05, respectively, as shown in Table 24. These means that increase in chemical energy phosphorus, potassium and herbicide input by 1% would result to 0.17, 0.12 and 0.05% increase in output energy, respectively. The coefficient of biological, thermal and chemical energy (nitrogen fertilizer) were -0.84, -2.15 and -2.50, respectively. Theseimplies that additional used of the inputs will have negative effect on the output.

The value of Return to Scale (RTS) for the equation (model V) was 2.16. The value greater than unity (1.0) implied increasing Return to Scale (IRS) for maize production in the surveyed region.These results indicates that 1% increase in all the energy inputs would result to 2.16% increase in the maize production.

The sensitivity analysis of energy inputs were presented in the last column of Table 24. Manual and mechanical energydrown the major MPP value of 27.14 and 15.28, respectively. These implies that an additional use of 1 MJ ha^{-1} from each of manual and mechanical energy would lead to an additional increase in yield of maize by 27.14, and 15.28 kg ha^{-1}, respectively.In other words, there is a higher potential for increasing the output by additional use of these inputs for maize production in the surveyed region. This is similar to what was obtained byMobtaker and Amanloo, (2004) for sensitivity analysis of maize productivity in Iran. They reported that machinery energy had thehighest MPP value (9.68) followed seeds, human labour and biocides with MPP value of 7.84, 4.04 and 2.14 respectively.

On the other hand, the MPP value for thermal, biological and chemical (nitrogen fertilizer) energies were found negative, indicating that there was excessive usage of these inputs for maize production in the surveyed region. These resulted to energy dissipation and as well imposing negative effects to environment and human health. Applying a better machinery management technique, employing the conservation tillage methods and also, controlling input usage by performance monitoring can help to reduce the diesel fuel and chemical energy (fertilizer) inputs and minimize their environmental impacts. Also, integrating a legume into the crop rotation, application of composts, chopped residues or other soil amendments may increases soil fertility in the medium term and so reduces the need for chemical fertilizer energy inputs.

The effect of direct and indirect energies (DE and IDE) on outputwas established as shown in Equation 73 (model VI). The coefficient of determination of the model was 0.94 as shown in Table 25, indicating that all the different energy inputs contributed immensely to the energy output. The variability in the energy inputs could be explained by this model up to 94%, indicatingthat all Durbin-Watson value was 2.15, indicating that the model developed was capable of predicting energy output at different energy inputs beyond the two seasons considered in this work. It means that the equation is valid beyond two seasons.

It was observed from the developed model that both direct and indirect energies had positive impact on output. The impact of direct and indirect energy were statistically significant ($p<0.01$). Theelasticity values for direct and indirect energies were 0.009 and 0.88, respectively as shown in Table 34. These imply that 1% increase in direct and indirect energies would led to 0.009 and 0.88% increase in output energy respectively. The impact of indirect energy (IDE) was more than the direct energy (DE) on output. Similar results can be seen in the study of Hatirli *et al.*(2005) for greenhouse tomato production.

The Marginal Physical Productivity values (MPP) for direct and indirect energies were 0.005 and 0.34, respectively, as shown in Table 25. This indicates that an additional utilization of 1MJha^{-1} of indirect and direct energies, would lead to an additional increase in yield by 0.005 and 0.34 kg ha^{-1},respectively.

Table 24: Econometric Estimation Results for Maize Production.

Endogenous variable:	**Maize yield (Y_i)**	
Exogenous variables	Coefficients	MPP
$Model\ V: \ln Y_i = \alpha_1 lnX_1 + \alpha_2 lnX_2 + \alpha_3 lnX_3 + \alpha_4 lnX_4 + \alpha_5 lnX_5 + \alpha_6 lnX_6 + \alpha_7 lnX_7 + \alpha_8 lnX_8 + e_i$		
1. Manual Energy (X_1)	0.60	27.14
2. Thermal Energy(X_2)	-2.15	-1.35
3. Mechanical Energy (X_3)	6.72	15.28
4. Biological Energy (X_4)	-0.84	-5.48
5. Chemical Energy N (X_5)	-2.50	-1.57
6. Chemical Energy P_2O_5 (X_6)	0.17	1.20
7. Chemical Energy K_2O (X_7)	0.12	1.13
8. Chemical Energy Herbicide(X_8)	0.05	0.37
Return to Scale (RTS)	2.16	
Durbin Watson Test (DW)	2.10	
R-square	0.98	

$$Model\ V: \ln Y_i = 0.60 lnx_1 - 2.15 lnx_2 + 6.72 lnx_3 - 0.84 lnx_4 - 2.50 lnx_5 + 0.17 lnx_6 + 0.12 lnx_7 + 0.05 lnx_8 \qquad R^2 = 0.98 \qquad (72)$$

Table 25: Econometric Estimation Results for Direct and Indirect Energy for Maize Production.

Endogenous variable:	**Maize yield (Y_i)**	
Exogenous variables	Coefficients (β_1)	MPP
$Model\ VI: \ln Y_i = \beta_1 lnDE + \beta_2 lnIDE + e_i$		
1. Direct Energy (DE)	0.009	0.005
2. Indirect Energy (IDE)	0.88	0.34
Return to Scale (RTS)	0.89	
Durbin Watson Test (DW)	2.15	
R-square	0.94	

$$Model\ VI: \ln Y_i = 0.009\ lnDE + 0.88\ lnIDE \quad R^2 = 0.94 \qquad (73)$$

4.9 Economic Analysis of Maize Cultivation

4.9.1 Cost of Energy input in the cultivation of Maize

The energy cost input in maize production are illustrated in Table 26. The total amount spent on maize cultivation varied from ₦80795.90 to ₦81920.00 in small farms and it varied from ₦75680.00 to ₦78777.00 and ₦72018.00to ₦74938.00 in medium and large farms, respectively, as shown in Table 35. The variation was caused majorly by the difference in price and quantity of thermal, mechanical and chemical energy which varied in each categories of farm.

The average total cost for producing maize per hectare in small, medium and large farms were ₦81520.56, ₦78344.26 and ₦73463.66, respectively, as shown in Table 27. There was a decrease in average input costfrom small to large farms. This can be attributed to total energy inputs in the farms which decreased from small to large farms.

4.9.2 Cost of Energyinput pattern for the cultivation of Maize

Itwasobservedthatinallthethreecategories offarms,manualenergy contributed the highest cost input,followedbychemicalandmechanicalenergy, respectively. Amount spent on manual energy in small, medium and large farms were ₦33716.66 (41.35%), ₦27399.98 (34.97%) and ₦25833.32 (35.16%), respectively, as shown in Figure 29. The was a decrease in the total cost for maize production from small to large farms, indicating that the cost of maize production can be reduced by increasing scale of production and mechanization level.

In small, medium and large maize farms,amount spent on chemical energy were₦24137.26 (29.60%), ₦22680.92 (28.90%), ₦21357.00 (29.07%),respectively. There was a variation in the cost of chemical energy which decreases from small to medium to large farms. Variation in unit price of fertilizers, quantity of fertilizer applied were observedduring survey in small, medium and large farms. Also, the cost of transporting fertilizers to the farms varies, thus contributed to the variation.

From Figure 29, the cost spent on mechanical energy in small, medium and large farms were ₦12399.98 (15.21%), ₦15633.32 (19.95%) and ₦13900.00 (18.92%), respectively.Cost incurred on thermal energy in small, medium and large farms were ₦10283.33 (13.92%), ₦11696.17(16.28%) and ₦11473.33 (15.93%), respectively. There was variations in the amount spent on mechanical and thermal energy from small to large farms. Small farms has the least cost spent on mechanical and thermal energy because planting and weeding operations were not mechanized. Medium farms has the highest cost spent on mechanical and thermal energy because some farms in medium farms categories acquired their tractor and implements rent services.The distance the tractor has to travel to get to the farms and fuel used in transporting the tractor down to the farm was considered in the computation.

In all the farm categories, Biological energy input has the minimum cost input of ₦983.33 (1.20%),₦916.00 (1.19%) and ₦900.00 (1.12%) of the total cost input in small, medium and large farms, respectively.

Considering theunitoperationsduringproduction(Figures30to32),amount spent on fertilizer application wasthe most cost- intensive operationinallthethreefarm categories. Amount spent on fertilizer application in small, medium and large farms were ₦28503.93, ₦26914.27 and ₦25457.00, respectively. These accounted for 34.96, 34.35 and 34.65% ofthetotalinputenergy in small,mediumandlarge farms, respectively. This clearlysupports the previous finding thatfertilizer applicationwasthemostenergyintensiveprocesses in maize production. High cost input in fertilizer application was due to high cost of fertilizer. A bag of fertilizer (50kg) was sold between ₦5500.00 to ₦6000.00. There was a decrease in the cost of fertilizer application from small to large farms. The decline in the cost spent on fertilizer application from small to large farms shows better energy utilization in medium and large farms, respectively. This may be due energy conservation practice.

About ₦8900.00(10.90%), ₦8233.22 (10.50%) and ₦7933.33 (10.79%) were spent on tillage operation in small, medium and large farms, respectivelyas shown in Figure 30 to 32. This was followed by land clearing which accounted for₦8433.33(10.34%), ₦8133.33(10.38%) and₦7566.66(10.29%)of the total cost in small, medium and large farms, respectively. These was within the finding of Diran *et al.,* (2015). They reported that the amount spent on tillage and land clearing ranges in Nigeria were between ₦ 3807.53 to ₦ 12763.29 and ₦ 1906.13 to ₦ 9153.56, respectively

As shown in Figure 30, the average cost spent on weeding, harvesting and planting per hectare in small farms were ₦9033.33 (11.08%), ₦8066.66 (9.89%) and ₦7483.33 (9.17%), respectively. while the amount spent on these operations per hectare in medium farms as shown in Figure 31 were ₦9013.33 (11.50%), ₦7833.33 (9.99%) and₦6166.67 (7.87%), respectively. Also, ₦8806.66 (11.98%), ₦7183.33 (9.77%) and₦5616.66 (7.64%) were spent on these operations in large farms, respectively, as presented in Figure 32.Also, the amount spent on transportation in the respective categories were ₦6333.33 (7.76%), ₦8250.00 (10.53%) and ₦7466.66 (10.16%), respectively.

The least cost input was spent on threshing operation in all the three farms.The amount spent on threshing operation in the respective categories were ₦4766.66 (5.84%), ₦3800.00 (10.53%) and ₦3433.33 (10.16%), respectively.

Table 26: Costof Energy Input and Output for Maize Cultivation per Hectare (₦/ ha)

	Cost Input (₦/ ha)								
Unit Operation	**Small farms**			**Medium farms**			**Large farms**		
	Farm 1	**Farm 2**	**Farm 3**	**Farm 1**	**Farm 2**	**Farm 3**	**Farm**	**Farm 2**	**Farm 3**
Land clearing									
Human energy	1600.00	1600.00	1500.00	1500.00	1400.00	1400.00	1400.00	1300.00	1300.00
Mechanical energy	2400.00	2500.00	2500.00	2500.00	2400.00	2400.00	2100.00	2200.00	2100.00
Thermal energy	4400.00	4400.00	4400.00	4300.00	4200.00	4300.00	4000.00	4100.00	4200.00
Tillage									
Human energy	1600.00	1600.00	1600.00	1500.00	1600.00	1600.00	1600.00	1500.00	1400.00
Mechanical energy	3000.00	2800.00	2800.00	2500.00	2500.00	2600.00	2300.00	2400.00	2400.00
Thermal energy	4500.00	4400.00	4400.00	4300.00	4000.00	4100.00	4100.00	4100.00	4000.00
Planting									
Human energy	6500.00	6500.00	6500.00	1400.00	1600.00	1500.00	1400.00	1300.00	1300.00
Mechanical energy	-	-	-	3000.00	2500.00	2500.00	2500.00	2500.00	2400.00
Thermal energy	-	-	-	1100.00	1100.00	1000.00	850.00	900.00	1000.00
Biological energy	950.00	1000.00	1000.00	950.00	950.00	900.00	950.00	900.00	850.00
Fertilizer application									
Human energy	7000.00	6500.00	7000.00	6500.00	6500.00	6500.00	6500.00	6500.00	6000.00
Chemical energy N	11000.00	11900.00	11050.00	10900.00	10100.00	10200.00	9200.00	9000.00	10100.00
P_2O_5	5500.00	5600.00	5670.00	5587.00	5529.90	5590.00	5430.00	5480.00	5355.00
K_2O	4445.90	4445.90	5400.00	4400.00	4445.90	4490.00	4158.00	4348.00	4300.00
Weeding									
Human energy	6500.00	6000.00	6500.00	4000.00	4500.00	4000.00	4000.00	4000.00	4200.00
Chemical energy (Herbicide)	2500.00	2300.00	2600.00	2300.00	2250.00	2250.00	2400.00	2100.00	2200.00
Mechanical energy	200.00	250.00	250.00	2000.00	2500.00	2500.00	2300.00	2400.00	2100.00
Thermal energy	-	-	.	240.00	250.00	250.00	250.00	240.00	230.00

Harvesting									
Human energy	8000.00	8200.00	8000.00	7500.00	8000.00	8000.00	7550.00	7000.00	7000.00
Threshing									
Human energy	800.00	850.00	800.00	750.00	750.00	700.00	750.00	750.00	750.00
Mechanical energy	3500.00	3500.00	3000.00	2500.00	2500.00	2500.00	2000.00	2000.00	2500.00
Thermal energy	600.00	650.00	600.00	550.00	550.00	600.00	500.00	500.00	550.00
Transportation									
Human energy	2000.0	2000.00	2000.00	3500.00	3500.00	4000.00	3500.00	3000.00	3500.00
Thermal\ energy	800.00	850.00	850.00	1500.00	1350.00	1400.00	1700.00	1500.00	1700.00
Mechanical energy	3000.00	4000.00	3500.00	3500.00	3000.00	3000.00	3500.00	2000.00	2000.00
Cost of energy Input (₦ /ha)	80795.90	81845.90	81920.00	78777.00	77975.80	75680.00	74938.00	72018.00	73435.00
Yield (kg/ha)	2830.00	2750.00	2700.00	3555.00	3513.00	3207.00	3485.00	3513.00	3357.00
Cost Output (₦ /ha)	141500.00	137500.0	155750.00	177750.00	175650.00	160350.00	174250.00	175650.00	167850.00

Table 27: Average Cost of Energy Input and Output for Maize Cultivation (₦/ha)

Cost Input (₦/ha) Unit Operation	Small farms	Medium farms	Large farms
Land clearing			
Manual energy	1566.66	1433.33	1333.33
Mechanical energy	2466.66	2433.33	2133.33
Thermal energy	4400.00	4266.66	4100.00
Tillage			
Manual energy	1600.00	1566.66	1500.00
Mechanical energy	2866.66	2533.33	2366.67
Thermal energy	4433.33	4133.33	4066.67
Planting			
Manual energy	6500.00	1500.00	1333.33
Mechanical energy		2666.66	2466.66
Thermal energy		1066.67	916.66
Biological energy	983.33	933.33	900.00
Fertilizer application			
Manual energy	6833.33	6500.00	6333.33
Chemical energy N	11316.67	10400.00	9433.33
P_2O_5	5590.00	5568.96	5421.67
K_2O	4763.93	4445.30	4268.67
Weeding			
Manual energy	6333.33	4166.66	4066.67
Chemical energy (Herbicide)	2466.66	2266.66	2233.33
Mechanical energy	233.33	2333.33	2266.67
Thermal energy		246.67	240.00
Harvesting			
Manual energy	8066.67	7833.33	7183.33
Threshing			
Manual energy	816.67	733.33	750.00
Mechanical energy	3333.33	2500.00	2166.67
Thermal energy	616.67	566.67	516.67
Transportation			
Manual energy	2000.00	3666.67	3333.33
Thermal energy	833.3333	1416.667	1633.33
Mechanical energy	3500.00	3166.667	2500.00
Cost of Energy Input (₦/ha)	81520.56	78344.24	73463.66
Yield (kg/ha)	2793.33	3371.66	3401.66
Cost Output (₦ /ha)	143125.00	168583.40	170083.30

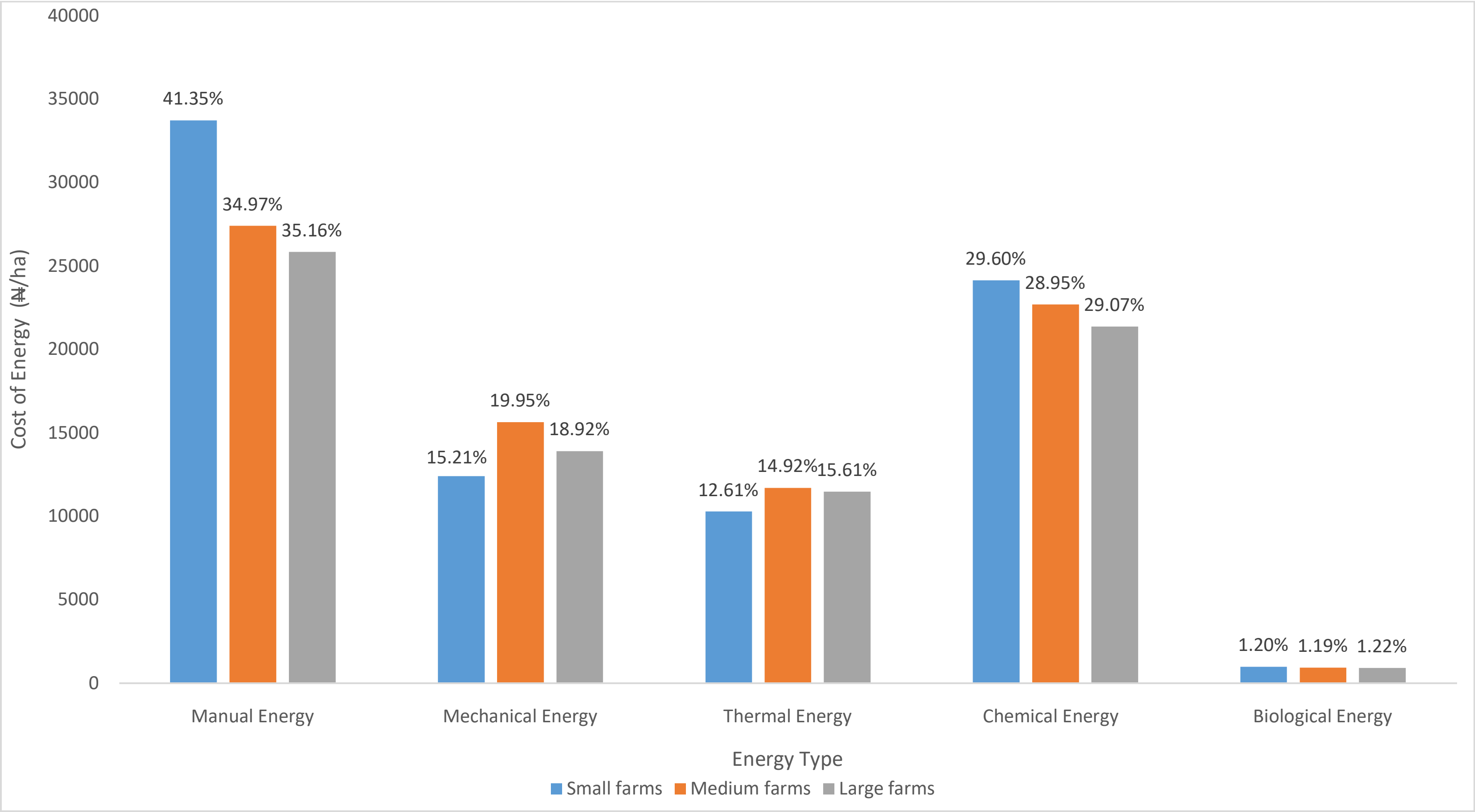


Figure 29: Cost of Energy use Pattern for MaizeCultivation

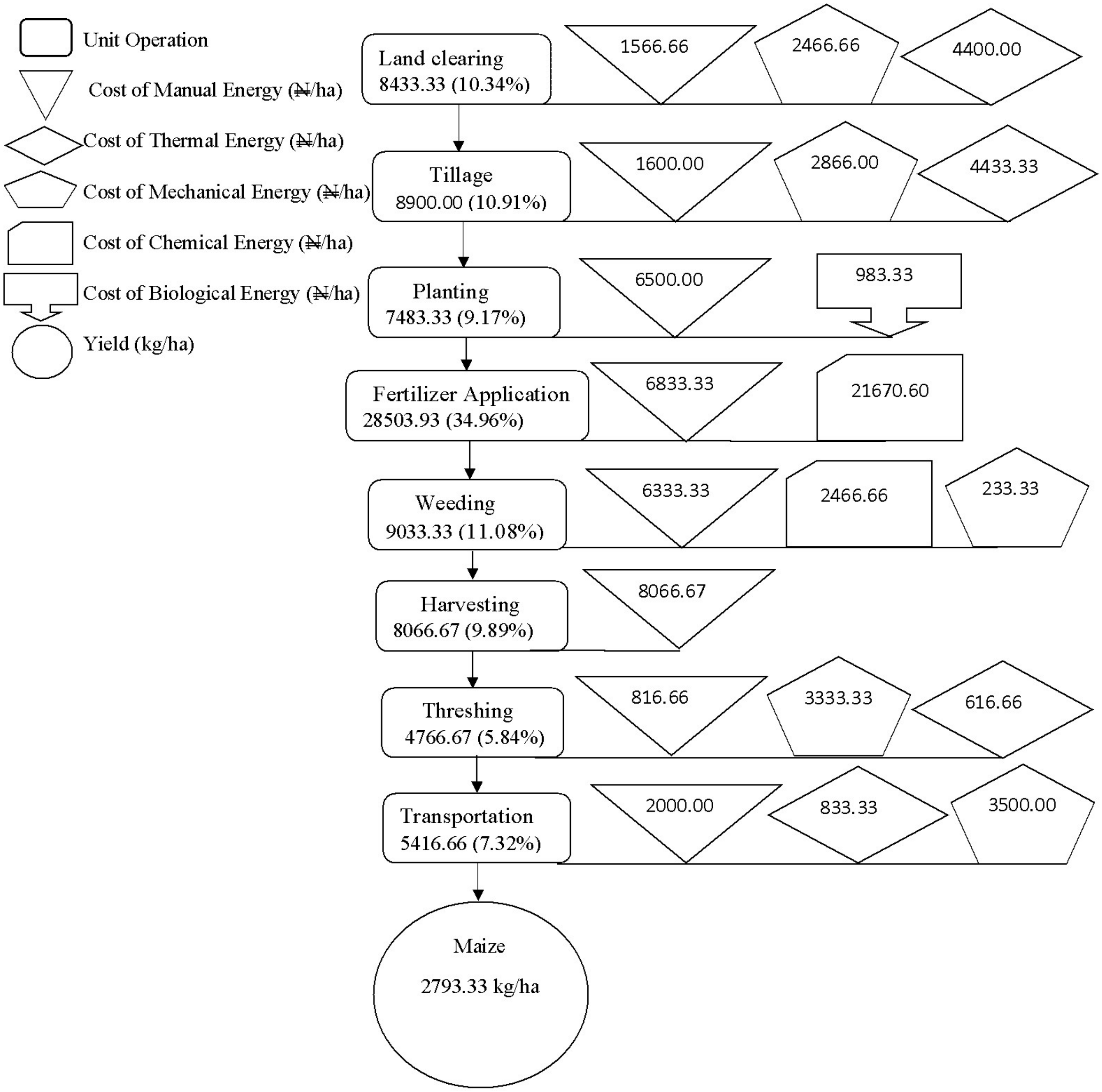


Figure 30: Economic FlowDiagraminaSmall Maize Farm

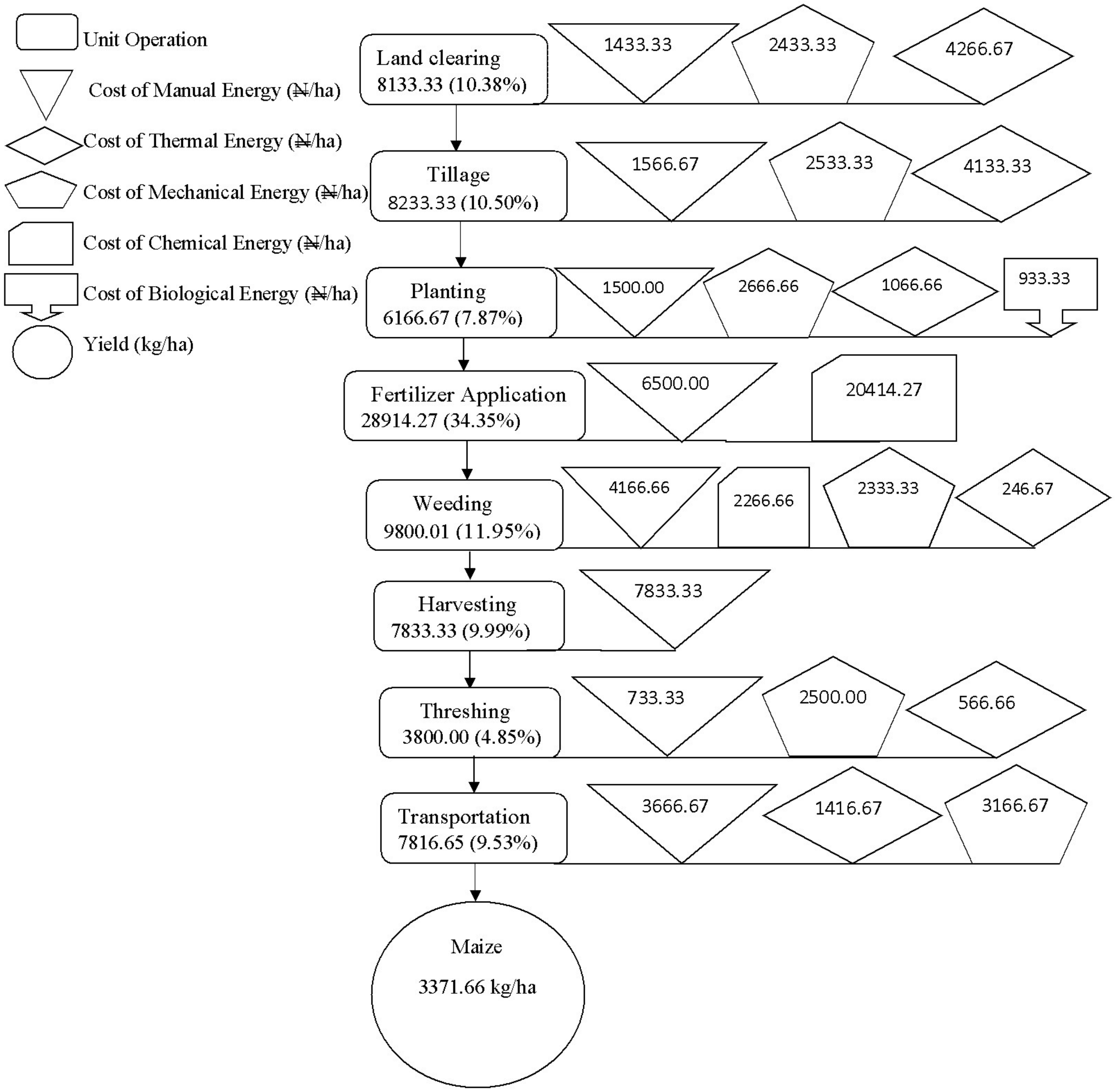


Figure 31: Economic FlowDiagraminaMedium Maize Farm

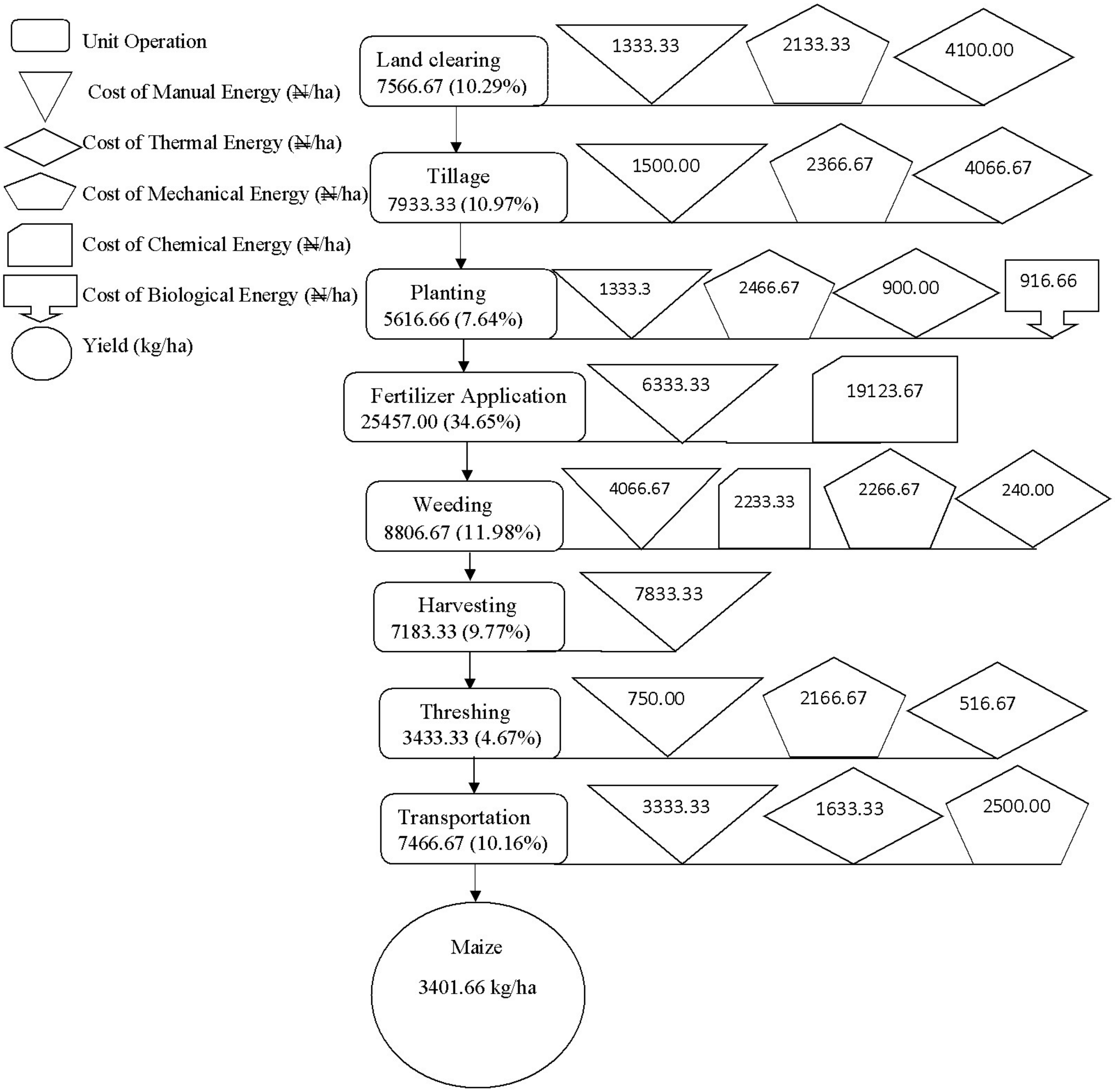
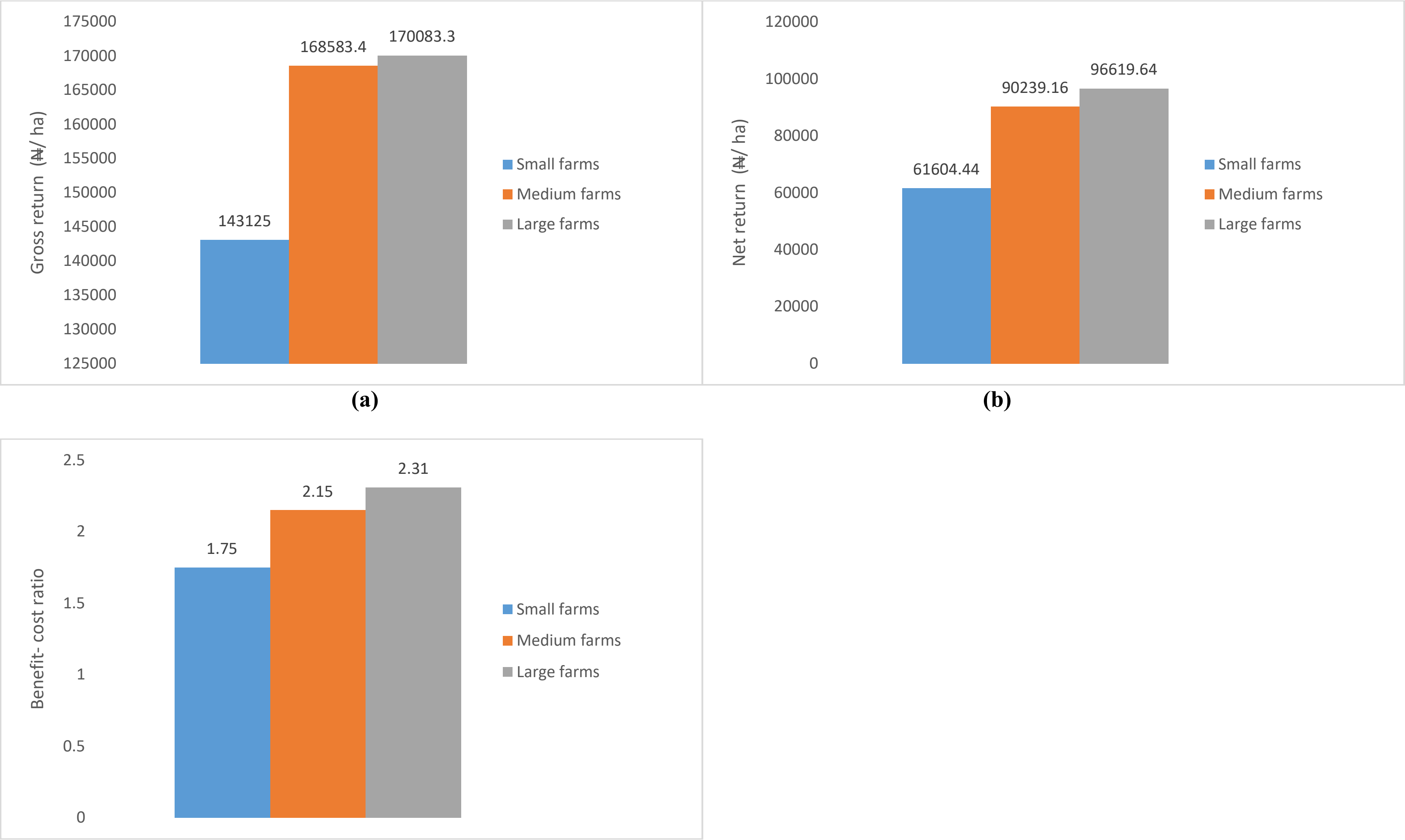


Figure 32: Economic FlowDiagraminaLarge Maize Farm

4.9.3 Economic Indicators for Maize Production

The gross return per hectare in small, medium and large farms were ₦143125.00, ₦ 168583.40, ₦170083.30, respectively, as shown in Figure 33 (a).The net return per hectare in small, medium and large farms were ₦61605.00, ₦90239.15, ₦96619.34, respectively, as shown in Figure 33 (b).Statistical inference shows that there is significant difference in net return per hectare due increase in level of mechanization from small to medium and large farms.There was an increase in the net return from small to large farms, indicating that more gain can be obtained in medium and large farms, respectively. The benefit-cost ratios for maize production in small medium, and large farmswere 1.75, 2.15 and 2.31, respectively, as show in Figure 33 (c). The value of benefit- cost ratio more than 1 indicates that maize production in the surveyed region was feasible from economic stand point. This means that for every naira invested in small, medium and large maize farms₦1.75, ₦2.15 and ₦2.31, respectively, were gained. These is within the benefit cost ratio obtained for maize production in Nigeria which varied from 1.79 to 4.48. (Diran *et al.,* 2015). There was an increase inthecost-benefit ratio fromsmalltolargemaize farms, indicating that more profit were obtainable in medium and large rice farms, respectively.



(a) **(b)**

(c)

Figure 33: Economic indicators of Maize Cultivation: Gross Return (a), Net Return (b), Benefit- Cost Ratio (c)

4.10 Energy Input in Yam Production

4.10.1 Energy Input in Yam cultivation

The input energy values used in yam cultivation are illustrated in Table 28.It was observed that the mode of energy input in all the unit operation were common to all the farms considered irrespective of the size of the farm. Energy input in the cultivation of yam varied from 197778.77 to 19941.62 MJ/ha in small farms and it varied from 19282.51 to 19565.31 MJ/ha and 18989.22 to 19086.46MJ/ha in medium and large farms, respectively, as shown in Table 28. There was little variation in the energy input in each farm category, these was because most of field operations were done manually in all the farms considered. The little variation in the energy input in each farm categorywas majorly caused by the different amount of chemical and biological energy input.

The average total energy inputs required for yam production in small, medium and large farms per hectare were 19835.08, 19392.17 and19024.37, respectively,as shown in Table 29.This is relatively higher than 7388.6 - 10888.66 MJ/ha obtained from cassava in Nigeria (Bamgboye and Kosemani, 2015). High energy input is attributed to high amount of biological energy input (yam sett). There was a noticeable variation in the average energy input per hectare. The variation was caused majorly by the different amount of biological energy input and chemical energy input. However, there was a decrease in the total energy input from small to large farms. Thisindicatesbetter utilizationof energyinthe medium and large farms, respectively.

4.11.2 Energy Use Pattern in Yam Cultivation

Energy resources used by the farmers in the three categories were manual, chemical (fertilizer and herbicide), mechanical, thermal and biological energy (yam seed). The pattern of energyuse obtained showed that biological andchemicalenergy were the highest energy input in all the three categories of farms. This indicates high usage of both biological and chemical energy in all the categories of farms. Biological energy contributed 9719.00, 9382.33 and 9157.00 MJ/hawhich accounted for 48.99, 48.38 and 48.00% of the total energy input in small, medium and large farms, respectively, as shown in Figure 34. High energy input from biological energy was attributed to high quantity of yam sett required for planting. Yam sett planted in the three categories of farms weigh between 95-185g.

The contributions of chemical energy in small, medium and large farms were 46.28% (9180.16MJ/ha), 46.46% (9111.33 MJ/ha) and 46.38% (8825.03 MJ/ha), respectively. High chemical energy input was attributed to high quantity of fertilizer usage which varied from small to large farms. Thisvariationmay beduetolackof adequateattentionor lackof concernfor energyconservation. However, large farms has the lowest chemical input which indicates better utilization of chemical energy in large farms.

In small farms, mechanical and thermal energy contributed 1.95% (372.0 MJ/ha) and 1.23% (244.75 MJ/ha), respectively. While in mediumfarms, these inputs were 1.99% (386.42MJ/ha)and 1.64%(318.8 MJ/ha), respectively. Also in large farms, they were 2.36% (449.44 MJ/ha)and 1.74% (322.2 MJ/ha), respectively.

Manual energy was the least in all the farms. The contributions of manual energy in small, medium and large farms were 1.52% (302.41 MJ/ha), 1.51%(293.26) and 1.50%(285.65 MJ/ha), respectively. Similar results are reported by researchers that energy input from manual energy contributed a small portion to the total energy input in agricultural crops production (Sartori *et al*., 2005; Strapatsa *et al*., 2006; Kizilaslan, 2009).

The share of indirect energy (biological, chemical, mechanical) in the total energy input in small, medium and large farmswere 97.25% (19287.92 MJ/ha), 96.85% (18780.11 MJ/ha) and 96.76% (18406.52 MJ/ha), respectively, as shown in Figure 35. Direct energy (manual, thermal) in small, medium and large farmswere 2.75% (547.16 MJ/ha), 3.15% (612.06 MJ/ha), 3.24% (617.85 MJ/ha), respectively. This result showed that yam production in the study area is mainly depended on indirect energy form dominated by biological and chemical energy (fertilizer).

Renewable energy in small, medium and large farms were 50.51, 49.81 and 50.36% of the total energy input, respectively. While non-renewable were 49.49, 50.11 and 49.64%, respectively.

Table 28: Energy Input and Output in the Production of Yam (MJ/ ha)

	Energy Input (MJ/ha)								
Unit Operation	**Small farms**			**Medium farms**			**Large farms**		
	Farm 1	**Farm 2**	**Farm 3**	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 1**	**Farm 2**	**Farm 3**
Land clearing									
Manual energy	47.75	48.00	47.25	46.02	46.03	47.00	44.50	44.00	44.46
Tillage									
Manual energy	64.48	65.55	64.92	64.80	63.22	64.90	62.45	62.71	62.95
Planting									
Manual energy	21.07	20.97	20.62	19.73	19.73	19.85	19.20	19.10	19.04
Biological energy	9757.00	9700.00	9700.00	9207.00	9340.00	9600.00	9160.00	9079.00	9157.00
Mulching									
Manual energy	5.45	5.43	5.55	5.30	5.30	5.35	5.50	5.12	5.20
Staking									
Manual energy	45.00	42.75	45.00	43.41	43.20	43.11	43.00	44.00	44.45
Fertilizer application									
Manual energy	12.99	14.00	16.52	14.90	14.00	14.00	13.90	14.50	13.22
Chemical energy N	7229.00	7229.00	7229.00	7110.00	7110.00	7100.00	7029.00	7029.00	7029.00
P_2O_5	1044.00	1044.00	1044.00	1044.00	1044.00	1044.00	1009.20	1009.20	1009.20
K_2O	616.50	616.50	616.50	548.00	548.00	548.00	479.50	479.50	479.50
Weeding									
Manual energy	25.14	25.07	24.78	24.00	24.90	24.90	24.90	24.95	24.90
Chemical energy (Herbicide)	322.00	328.00	322.00	312.00	312.00	314.00	304.00	304.00	314.00
Mechanical energy	380.80	287.00	384.25	360.80	257.00	257.00	344.25	344.25	247.00
Harvesting									
Manual energy	56.47	56.41	56.70	54.00	54.90	55.65	52.71	51.96	51.80
Transportation									
Manual energy	22.44	23.44	23.60	21.60	19.44	20.60	19.50	19.44	19.60
Thermal energy	248.75	237.00	248.5	310.70	335.00	310.70	332.20	329.80	334.60
Mechanical energy	42.78	35.65	35.65	96.25	91.97	96.25	142.65	136.89	133.30
Energy Input (MJ/ha)	19941.62	19778.77	19835.08	19282.51	19328.69	19565.31	19086.46	18989.22	19024.37
Yield (kg/ha)	11600.00	12075.00	12085.00	11650.00	12114.50	12210.00	11840.00	12600.00	12104.50
Energy Output (MJ/ha)	57420.00	55563.50	59820.75	57667.50	59966.75	59078.25	58608.00	62370.00	59917.25

Table 29: Average Energy Input and Output in the Production of Yam (MJ/ ha)

	Energy Input (MJ/ha)		
Unit Operation	**Small farms**	**Medium farms**	**Large farms**
Land clearing			
Manual energy	47.66	46.35	44.32
Tillage			
Manual energy	64.98	64.30	62.70
Planting			
Manual energy	20.88	19.77	19.11
Biological energy	9719.00	9382.33	9132.00
Mulching			
Manual energy	5.47	5.31	5.27
Staking			
Manual energy	44.25	43.24	43.81
Fertilizer application			
Manual energy	14.50	14.30	13.87
Chemical energy N	7195.67	7106.67	7029.00
P_2O_5	1044.00	1044.00	1009.20
K_2O	616.50	548.00	479.50
Weeding			
Manual energy	24.99	24.60	24.91
Chemical energy (Herbicide)	324.00	312.66	307.33
Mechanical energy	350.68	291.60	311.83
Harvesting			
Manual energy	56.52	54.85	52.15
Transportation			
Manual energy	23.16	20.54	19.51
Thermal energy	244.75	318.8	332.20
Mechanicalenergy	38.02	94.82	137.61
Energy Input (MJ/ha)	19835.08	19392.17	19024.37
Yield (kg/ha)	11734.17	11991.50	12181.50
Energy Output (MJ/ha)	57131.17	58904.17	60298.42

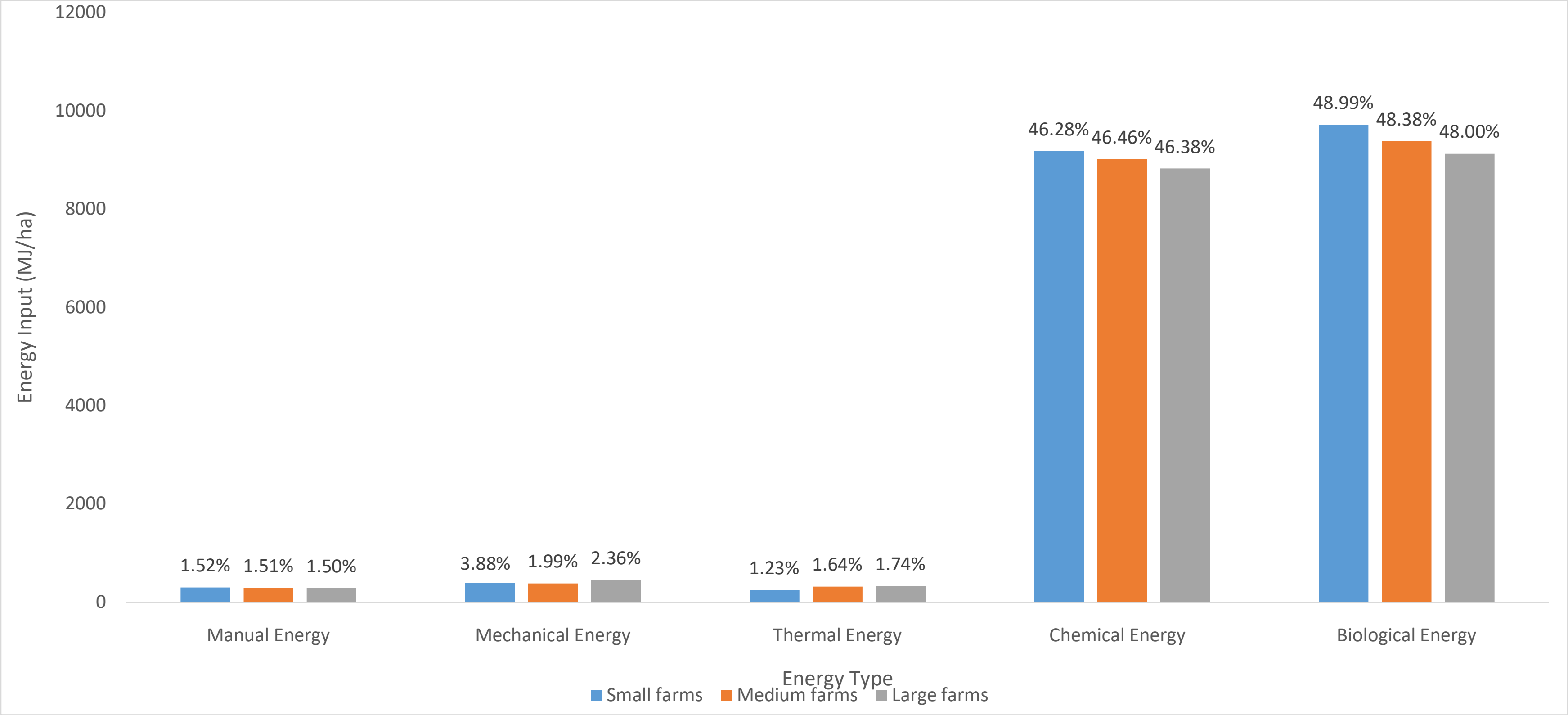


Figure 34: Energy Use Pattern for Yam Cultivation

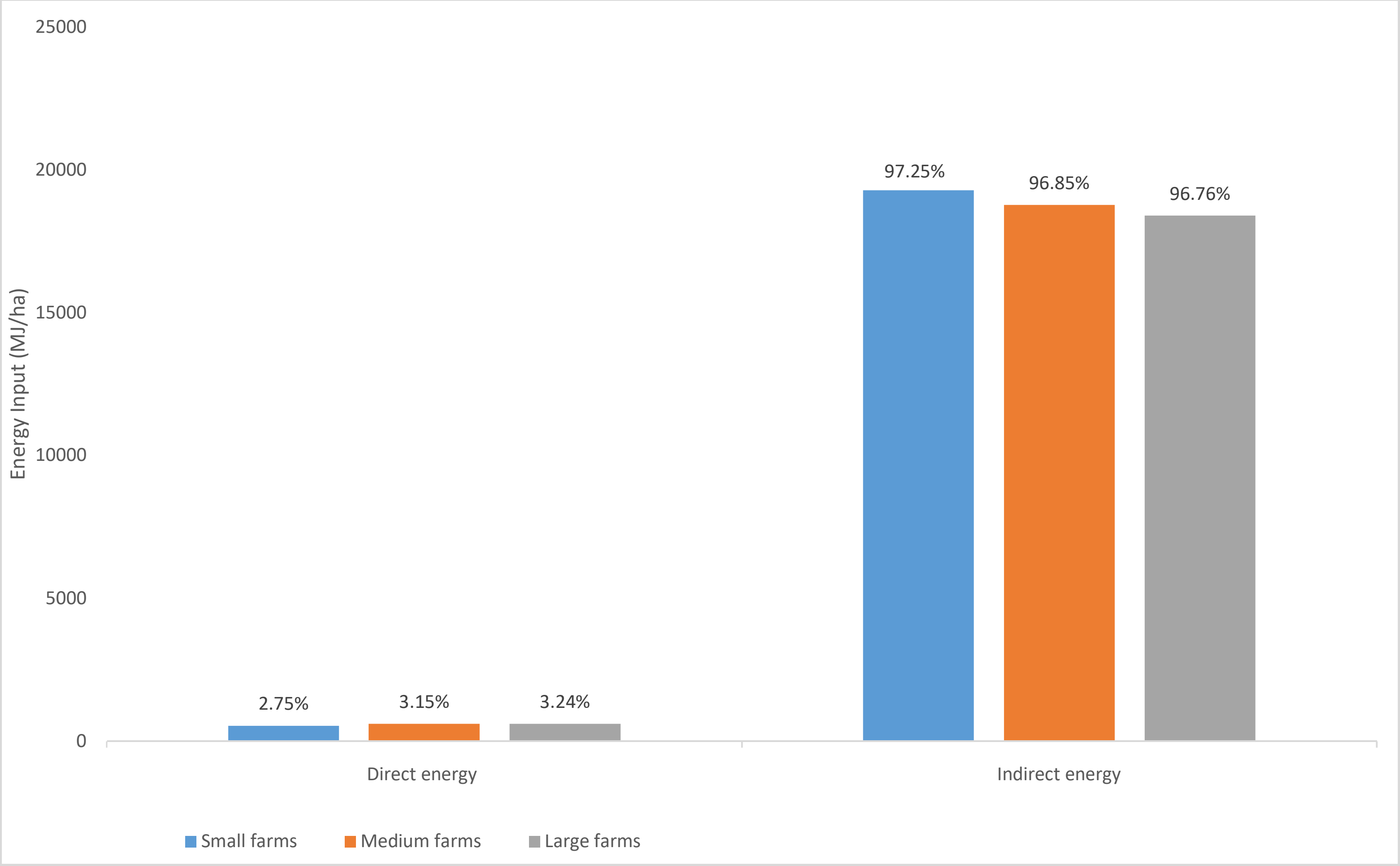


Figure 35: Distribution of Energy Forms in Yam Cultivation (MJ/ ha)

Operation wise, energy inputs in small, medium and large farms are illustrated in Figure 36 to 38. Planting and fertilizer application were observedto require the highest energy input in all the farms.Planting operation consumed about 9739.88, 9402.10 and 9151.00 MJ/ha which accounted for 49.10, 48.48 and 48.10% of the total energy input in small, medium and large farms, respectively. Fertilizer application consumed 8870.67, 8712.96 and 8531.57 MJ/ha which accounted for 44.77, 44.93 and 44.84% of the total energy input in small, medium and large farms, respectively. High energy input in planting and fertilizer application was due to high amount of biological energy (yam sett) and fertilizer usage during cultivation. Therewerenoticeablevariationsinthe yam sett and fertilizer duringthestudy. The quantity of yam sett and fertilizer consumed decreased from small to large farms. This trend shows that there was lackof concernfor energyconservation in planting and fertilizer application operations in small and medium yam farms. Farmersbelonging to these categories of farms believedthat yield can be increased by increasing the size of yam sett planted, thus further contributed to energy used in planting operation.

In small farms,weeding, transportation and tillage accounted for3.53% (699.68 MJ/ha), 1.54% (305.93 MJ/ha) and 0.28% (64.98 MJ/ha) of the total energy, respectively. While, harvesting, land clearing and staking accounted for0.33% (56.52 MJ/ha), 0.23% (47.66 MJ/ha) and0.22% (44.25 MJ/ha)of the total energy, respectively,as shown in Figure 36. In medium farms, weeding, transportation and tillage accounted for 3.24% (628.86MJ/ha), 2.23% (434.1 MJ/ha) and 0.22% (43.34MJ/ha) of the total energy, respectively. While, harvesting, land clearing and staking accounted for 54.85 (0.28%), 46.35 (0.23%), and 43.24 MJ/ha (0.22%) of the total energy, respectively,as shown in Figure 37. In large farms, weeding, transportation and tillage accounted for3.38% (644.08MJ/ha),2.57% (489.32 MJ/ha) and 0.32% (62.79 MJ/ha) of the total energy, as shown in Figure 38. While, harvesting, land clearing, and staking accounted for0.27% (52.15 MJ/ha),0.24%(44.32MJ/ha) and 0.23% (43.81MJ/ha), respectively.

FromtheTablesand Figures,itwasobservedthatmulching accounted for the least portion in all the farms. It accounted for0.02% (5.47 MJ/ha), 0.02% (5.31 MJ/ha) and 0.02% (5.27MJ/ha) of the total energy in small, medium and large farms, respectively.

4.11.3 Energy Output in Yam Cultivation

The average yield per hectare for yam cultivation in small, medium and large farm category were 11734.17, 11991.50 and 12181.50 MJ/ha, respectively, as shown in Table 29. Average yield obtained in small, medium and large farms were within the average yield of yam in Nigeria which varies from 10000-150000 kg/ha (FAO, 2010). The energy outputs obtained in small, medium and large farms were 57131.17, 58904.17, 60298.42 MJ/ha, respectively, as shown in Table 29.

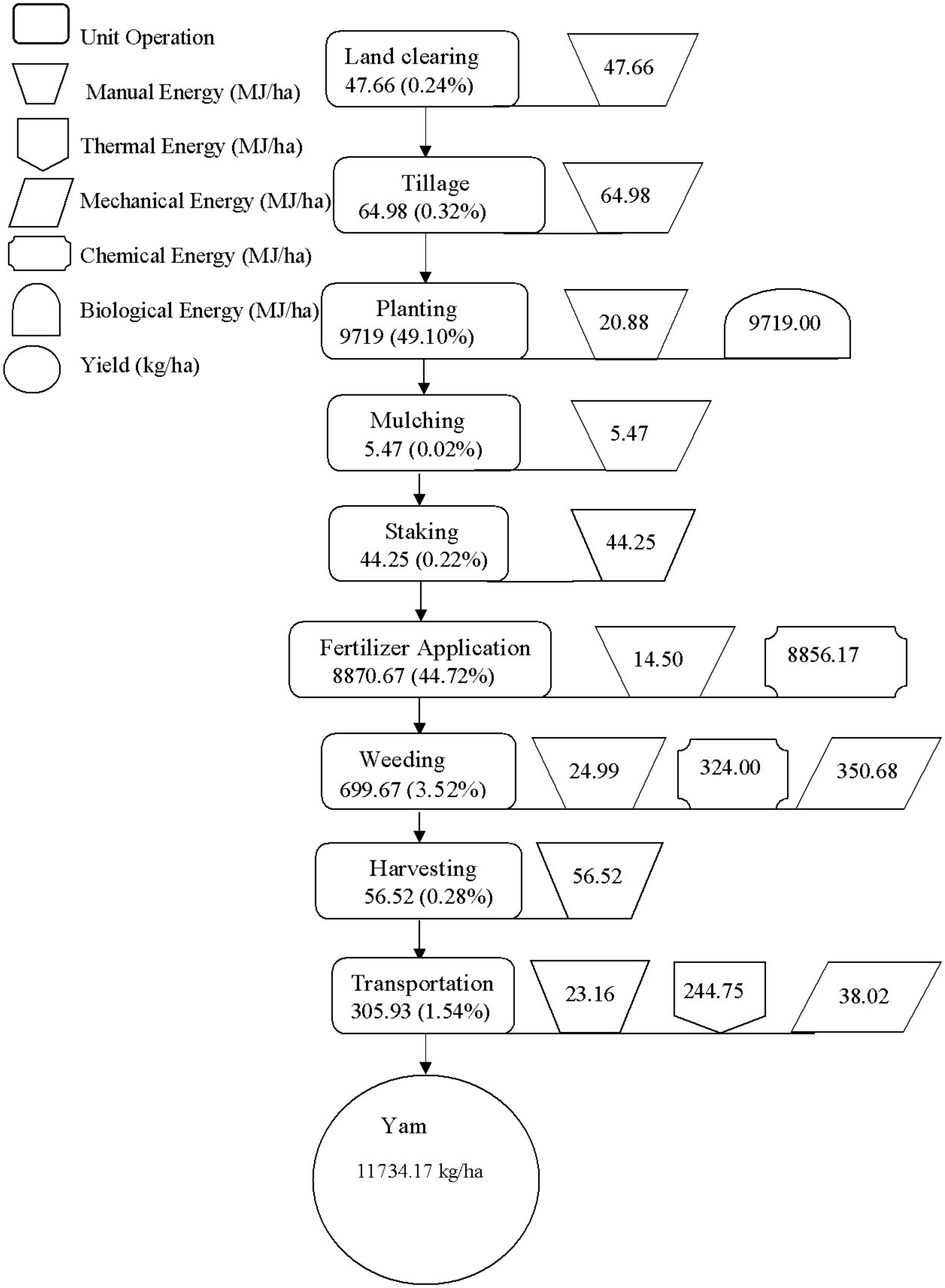


Figure 36:EnergyFlowdiagraminaSmall Yam Farm

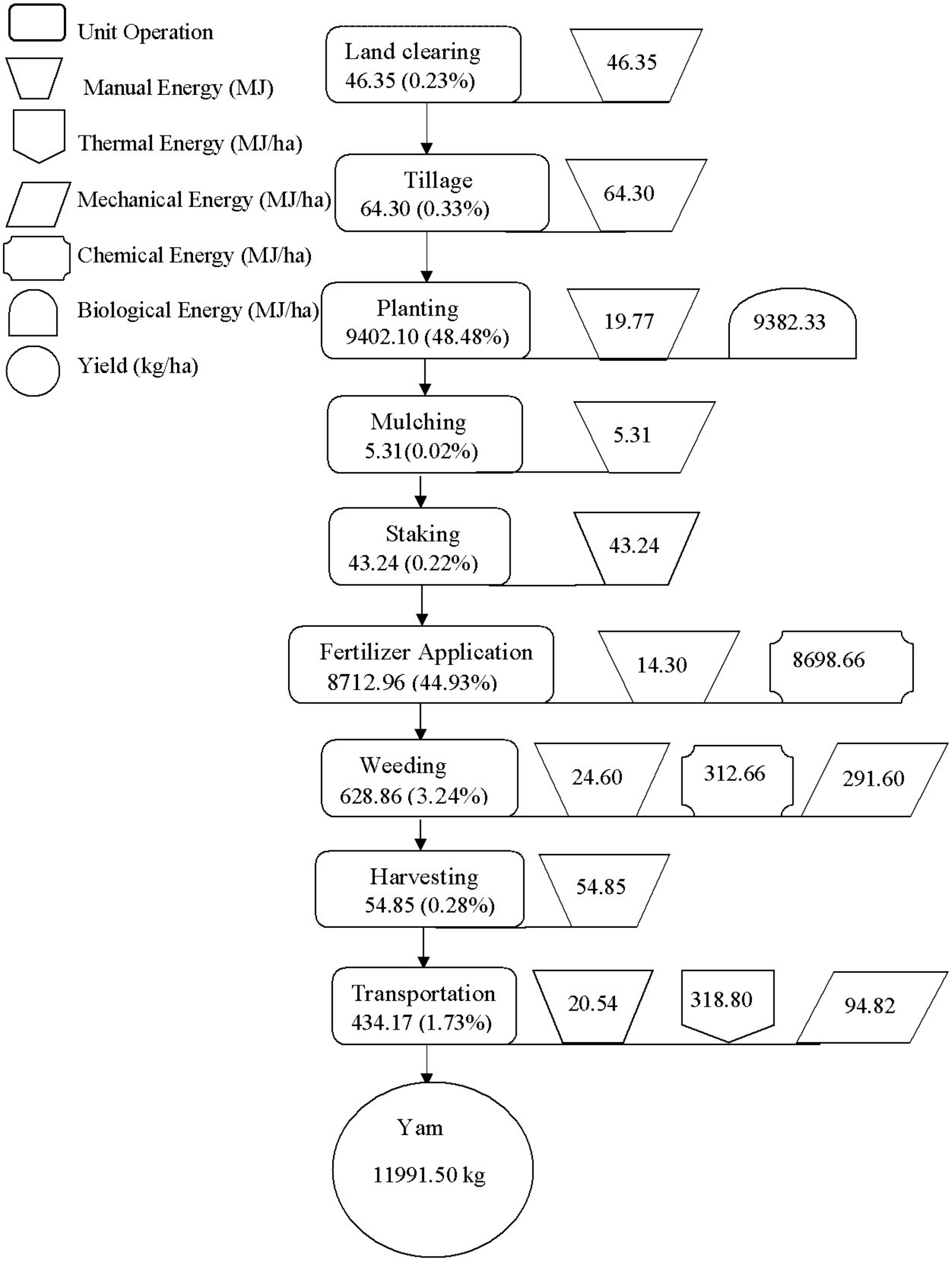


Figure 37:EnergyFlowdiagraminaMedium Yam Farm

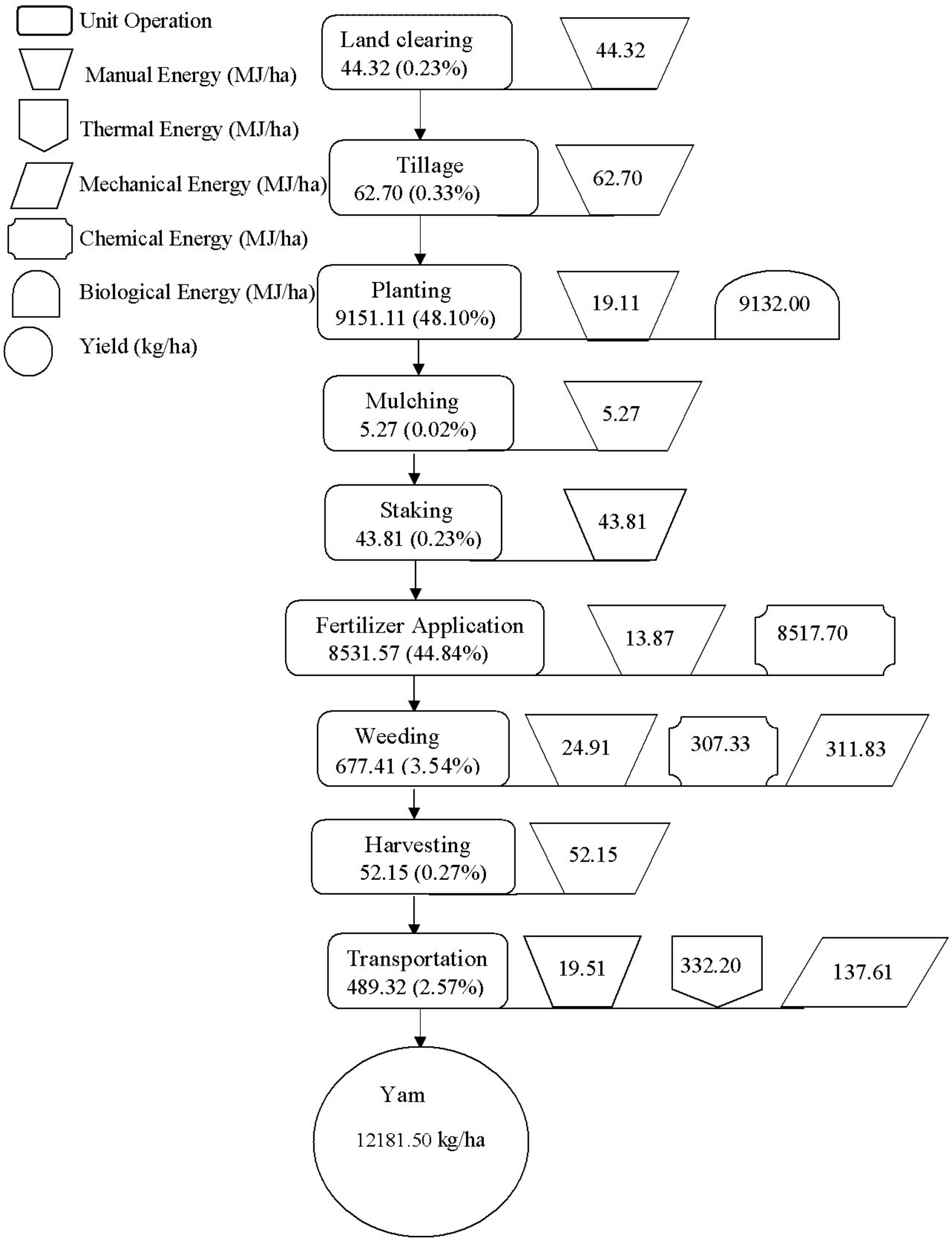


Figure 38:EnergyFlowdiagraminaLarge Yam Farm

4.11.4 Energy Indicators in Yam Cultivation

4.10.4.1The net energy values

The net energy values for yam production in small, medium and large farms were 37296.09, 39512.00 and 41274.05 MJ/ha, respectively, as shown in Figure 39 (a). The net energy value increases from small to large farms, indicating that more energy was gained in medium and large farms than in small farms. The net energy values was lower to 46,655.77 MJ/ha MJ/ha obtained by Bamgboye and Kosemani (2015) for cassava in Nigeria. Higher net energy value from cassava was due to higher yield of cassava (9960 kg/ha) as compared to what was obtained from this study.

4.10.4.2 Energy productivity

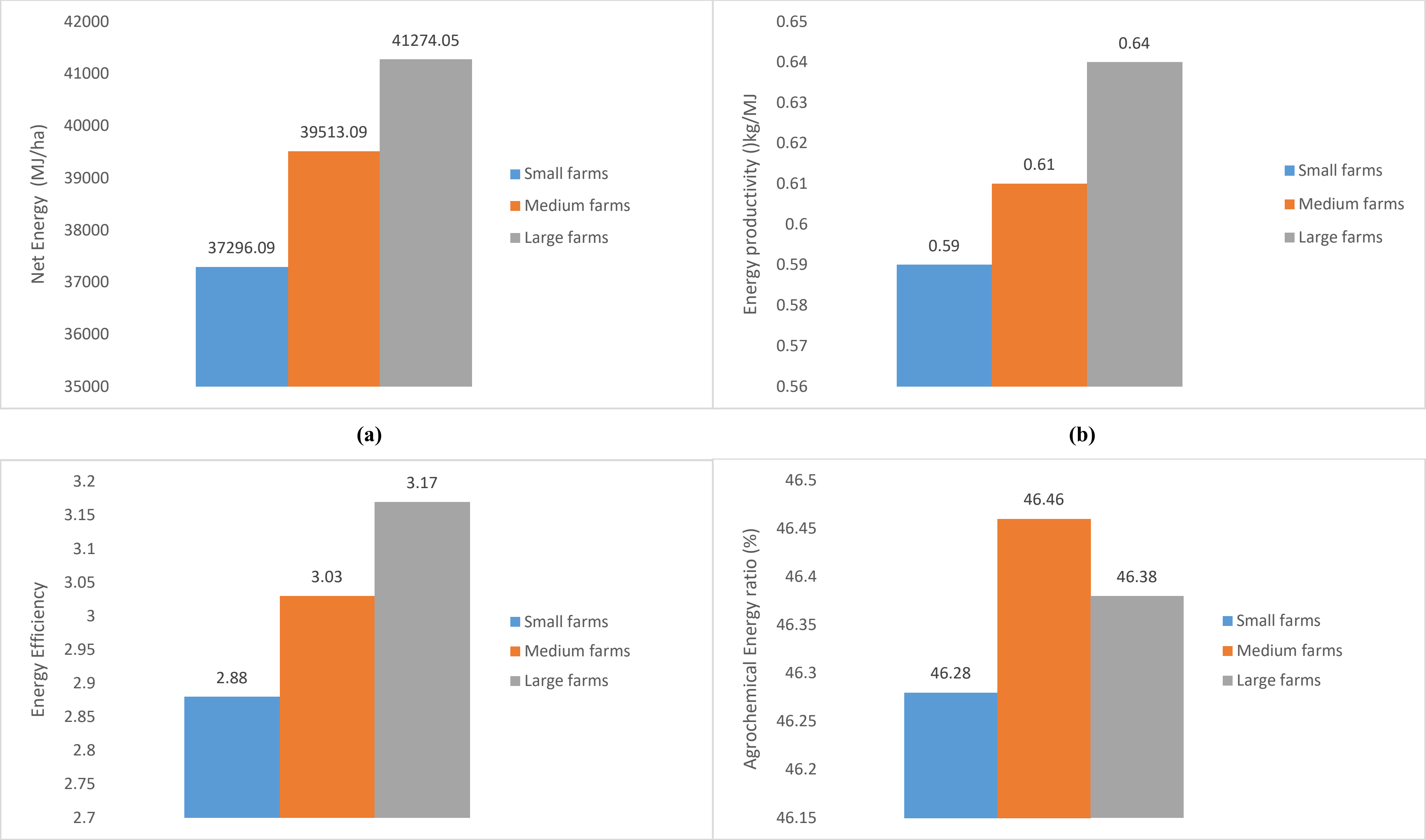
Energy productivity for yam production on small, medium and large farms were 0.59, 0.61 and 0.64 kg/MJ, as shown in Figure 39 (b). This indicated that 0.59, 0.61 and 0.64 kg of yam were produced when 1MJ of energy was consumed in small, medium and large farms, respectively.There was an increase energy productivity from small to large farms, indicating that more kilograms of yam is produced per unit energy (1MJ) input in medium and large farms than small farms.In a similar study, the average energy productivity of sweet orange production was 0.88 (Jekayinfa *et al.,* 2014).

4.10.4.3 The energy efficiency

From Figure 39 (c), the average energy efficiency in small, medium and large yam farms were 2.88, 3.03 and 3.17, respectively,indicating that energy were efficiently utilised. The energy efficiencies increased from small to large farm, indicating that energy was better utilized in medium and large farms, respectively. This finding is a likely reason why Benue State is noted as a major yam producing state in Nigeria. The value obtained for energy efficiency was quite lower compared to that obtained for Cassava (7.01) in Nigeria by Bamboye and Kosemani,(2015).The higher energy efficiency value indicated that a higher yield per hectare was obtained in the study area and the yam farmers are quite efficient in terms of energy use. In other researches, energy use efficiency reported for different crops were 2.8 for wheat, 4.8 for cotton, 3.8 for maize and 1.5 for sesame (Canakci *et al*, 2005), 2.95 and 3.5 for sunflower production in Turkey and Chile, respectively.

4.10.4.3 Agrochemical energy ratio

Agrochemical energy ratios of yam production in the agro-ecosystems for the respective categories as shown in Figure 39 (d) were 46.28, 46.46 and 46.38%, indicating that more energy was consumed per fertilizer and chemical inputs production. Excessive use of chemical energy input in agriculture may create serious environmental consequences such as nitrogen loading in the environment and receiving waters, poor water quality, carbon emissions and contamination of the food chain (Khan *et* *al*., 2009). Integrating a legume into the crop rotation, application of composts, chopped residues or other soil amendments may increases soil fertility in the medium term and so reduces the need for chemical energy inputs from fertilizer.



(a) **(b)**

(c) **(d)**

Figure 39: Energy Indicators Input in Yam Cultivation: Net Energy (a), Energy Productivity, (b) Energy efficiency (c) and Agrochemical ratio (d)

4.10.5 Econometric Model estimate of Yam Production

The result of the interaction among the input energy as it affect the energy output for yam cultivation are as shown in Table 30 and represented by Equation 74. From equation 74, the coefficient of determination is 0.96, indicating that all the different energy inputs contributed immensely to the energy output. The variability in the energy inputs could be explained by this model up to 96%. From Table 30, Durbin-Watson value was 2.12, indicating that the model developed was capable of predicting energy output at different energy inputs beyond the two seasons considered in this work. It means that the equation is valid beyond two seasons.

The results obtained revealed that manual, thermal, mechanical, biological and chemical (herbicide) weresignificant ($p<0.05$) in yam production.On the other hand, the impacts of chemical energies (nitrogen and potassium fertilizer) on yield were estimated statistically insignificant ($p>0.05$)as shown in Table 30.

The estimated regression coefficients for the model are presented in Equation 74. Chemical energy (phosphorus fertilizer and herbicide) and biological energy had the highest coefficient of 0.60, 0.59and 0.16 respectively, on output. With respect to the obtained results, increasing energy obtained from chemical energy (phosphorus fertiliser and herbicide) by 1% would lead to additional increase in yield by 0.60, 0.60 and 0.16 %, respectively.Ramedani *et al.*(2011) estimated an econometric model for soybean production in Iran. Theyreported that the inputs of seed (biological energy) had significant impacts on improving the yieldof soybean.The coefficient of mechanical, thermal and nitrogen fertilizer were 0.15, 0.08 and 0.03, respectively as shown in Equation 74. Increasing energy obtained from mechanical, thermal and nitrogen fertilizer by 1% would lead to additional increase in yield by 0.15, 0.08 and 0.03, respectively. Manual energy and chemical potassium fertilizer had negative coefficient of -0.15 and -0.11, respectively. Increasing manual energy and chemical potassium fertilizerby 1% would lead to decrease in yieldby 0.15and 0.11, respectively.

The major Marginal Physical Productivity values (MPP) were drowns by chemical energy (herbicide), chemical energy (phosphorus) and mechanical energyas shown in Table 30. The MPP values obtained were 22.4, 6.76 and 4.43, respectively. This implies that an additional use of 1 MJ ha^{-1} from each of the chemical energy (herbicide),chemical energy (phosphorus fertilizer) and mechanical energy would lead to an additional increase in yield value of yam by 22.4, 6.76and 4.43kg ha^{-1}, respectively. In other words, there is a potential for increasing output by additional use of these inputs for yam production in the surveyed region.On the other hand, the MPP value of manual and potassium fertilizer energy were found negative, indicating that there was excessive usage of these inputs for rice production andadditional use of these inputs would contribute negatively to the output, resulting to energy dissipation and as well as imposing negative effects to environment and human health.

Table 30: Econometric Estimation Results of yam Cultivation

Endogenous variable: Exogenous variables	Yam yield (Y_i)	
	Coefficients	MPP
$Model\ VII : \ln Y_i = \alpha_1 lnX_1 + \alpha_2 lnX_2 + \alpha_3 lnX_3 + \alpha_4 lnX_4 + \alpha_5 lnX_5 + \alpha_6 lnX_6 + \alpha_7 lnX_7 + \alpha_8 lnX_8 + e_i$		
1. Manual Energy (X_1)	-0.15	-6.04
2. Thermal Energy (X_2)	0.08	3.56
3. Mechanical Energy (X_3)	0.15	4.43
4. Biological Energy (X_4)	0.16	0.21
5. Chemical Energy N (X_5)	0.03	0.06
6. Chemical Energy P_2O_5 (X_6)	0.60	6.77
7. Chemical Energy K_2O (X_7)	-0.11	-2.47
8. Chemical Energy Herbicide(X_8)	0.60	22.42
Return to Scale (RTS)	1.38	
Durbin Watson Test (DW)	2.12	
R-square 0.96		

$Model\ VII: \ln Y_i = -0.15 lnx_1 + 0.08 lnx_2 + 0.15\ lnx_3 + 0.16 lnx_4 + 0.03 lnx_5 + 0.60 lnx_6 - 0.11 lnx_7 + 0.60 lnx_8\, R^2 = 0.96)$ (74)

Table 31: Econometric estimation results for direct and indirect energies for yam production

Endogenous variable:	**Yam yield ($\mathbf{Y_i}$)**	
Exogenous variables	Coefficients (β_1)	MPP
$ModelVIII : \ln Y_i = \beta_1 lnDE + \beta_2 lnIDE + e_i$		
1. Direct Energy *(DE)*	0.54	10.90
2. Indirect Energy (IDE)	0.60	0.377
Return to Scale (RTS)	1.14	
Durbin Watson Test (DW)	1.88	
R-square	0.92	

$$Model\ VIII : \ln Y_i = 0.54 lnDE + 0.60 lnIDE + e_i \qquad (R^2 = 0.92) \qquad (75)$$

This result showed the importance of the role of the mechanization in yam production.Efforts should be made at increasing the level of mechanisation so as to be self-sufficient in yam production in Nigeria.

The sum of the coefficients was 1.38, as shown in Table 30. The value greater than unity (1) implies increasing return to scale for yam production in the region. These result indicates that 1% increase in the total energy inputs would result by 1.38% increase in yamyield.Therefore, increasing the total energy input would increase the output in the surveyed region.

The model developed to establish the relationship between the indirect energies, direct energies and output for yam cultivation was shown in Equation 75. The R^2 (coefficient of determination) for the model was 0.99, implying that around 99% of the variability in the energy inputs was explained by the model. Direct and indirect energy were statistically significant at 1% level. Durbin-Watson value was 1.88,as shown in Table 31. This indicated that the model developed was capable of predicting energy output at different energy inputs beyond the two seasons considered in this work. It means that the Equation is valid beyond two seasons.

The degree of Returns to Scale for the model (VIII) was 1.14, as shown in Table 31. The value of return to scale greater than 1 implies increasing return to scale for yam production in the region. These results indicate that 1% increase in the total energy inputs would results to 1.38% increase in the yam production. Therefore, increasing the total energy input would not increase the output in the surveyed region.

The results of model developed between direct and indirect energies showed that boththe forms of energy had the expected sign. The coefficient of direct and indirect energies were 0.54 and 0.60, respectively, as shown in Equation 75. Both direct and indirect energies had positive impact on yield and were significant ($p<0.01$). The impact of indirect energies (IDE) was more than direct energy (DE) on yield. As shown in Table 44, the marginal physical productivity values (MPP) for IDE and RE were 10.90 and 0.37, respectively. This indicated that an additional utilization of 1 MJ in the indirect, would lead to an additional increase in yield by 10.90 kg ha^{-1}. In other words, there is a higher potential for increasing output by additional use of these inputs for yam production in the surveyed region.Similar results can be seen in the study of Hatirli *et al.*(2005) for greenhouse tomato production.

4.11 Economic Analysis of Yam Production

4.11.3 Cost of EnergyInput in Yam Cultivation

The energy costinput in yam production are illustrated in Table 32. Total amount spent on yam cultivation varied from ₦289773.00 to ₦297849.00 in small farms and it varied from ₦282293.90 to ₦289057.50 and ₦283363.00 to ₦288060.30 in medium and large farms, respectively, as shown in Table 32. The variation was caused majorly by the difference in price and quantity of biological, thermal, mechanical and chemical energy which decreases from small to large farms.

The average total cost of producing yam per hectare in small, medium and large farms were ₦292578.30, ₦286015.10 and ₦284972.00, respectively, as shown in Table 33. There was a decreasesin the average cost of yam production from small to large farms. This showed that less cost input was needed in the large farms than in the medium and small, respectively.The energy cost input is relatively higher than ₦ 166490.60 obtained from yam in Nassarawa (Jonathan and Anthony, 2012). This was due to low cost input in labour (₦38592.00)and fertilizer (₦10804.5) as compared to what was obtained in this study.

4.11.2 Cost of Energy pattern in Yam Cultivation

Amount spent onmanualenergy followed by biological was the highest cost input in all the farms. Amount spent on manual energy on small, medium and large farms were ₦131850.00 (45.06%), ₦127926.7 (44.72%) and ₦126673.30 (44.45%), respectively, as shown in Figure 40. High cost of manual energy was because most operations were performed manually in all the farms. This means that labour was the most important variable cost in yam production. Oguntade *et al.*(2010) reported that the labour cost of production yam in Oyo State, Nigeria was ₦117540.50 which accounted for 78.1% of the production cost. High percentage (78.1%) of manual energy cost obtained in their study was because all operations were done manually, low cost was spent onbiological energy and fertilizer was not used in their production.Minisett(25g to 50g) was used as their planting material which accounted for ₦33000 (21.9%) compared to (95-185g) obtained from this study.

In small, medium and large farms, ₦127000.00, ₦125000.00 and ₦12466.70 which accounted for 43.40, 43.70 and 43.74% of the total cost, respectively, were spent on biological energy. Therewasnoticeablevariationsinthe energy input from biological energy (yam sett), this translate to the variation in cost input.Thisvariationmay beduetolackof adequateattentionor lackof concernfor energyconservation.In a similar study, Planting materials (biological energy) account for about 50% of the cost of production and the cost of labour (manual energy) accounts for over 40% (Nweke *et al.*, 1991)

Amount spent on chemical and mechanical energy in small farmswere ₦29553.00 and ₦3316.67which accounted for 10.10 and 1.13% of the total cost,respectively. In medium farms,₦

26810.90 and ₦ 5216.67 which accounted for 9.37 and 1.82% of the total cost were spent chemical and mechanical energy, respectively. While, in large farms,₦26163.67 and ₦ 6366.67 which accounted for 9.18 and 2.23% of the total cost were spent on these operations, respectively.

Amount spent on thermal energy was the least in all the farms. Amount spent on thermal energy in small, medium and large farms were₦858.67.67, ₦1060.87 and ₦1101.76 which accounted for 0.29, 0.37 and 0.38% of the total cost, respectively, as shown in Figure 40. Low cost input in mechanical and thermal energy indicates low level of mechanization in the respective categories.

Considering theunitoperationsduringproduction(Figures41to43),the highest cost input was spent on planting and fertilizer application inallthethreefarms. Amount spent on planting per hectare in small medium and large farms were ₦139750.00, ₦137416.70, ₦137050.00which accounted for 47.76, 48.04 and 48.07% of the total cost,respectively. High cost spent on planting was due to high amount of biological energy (yam sett) used in all the farms. There was a noticeable variation in amount of biological energy required during survey. This translates to the variation in the amount spent on planting.

Amount spent on fertilizer application in small, medium and large farms per hectare were ₦34653.00, ₦31270.90 and ₦30703.67 which accounted for 11.84, 10.93 and 10.77 % of the total cost, respectively. Similarly, high cost spent on fertilizer application was due to high cost of chemical energy (fertilizer) duetolackof adequateattentionor lackof concernfor energyconservation.

In small yam farms, ₦22050.00, ₦21500.00 and ₦20500.00 which accounted for 7.53, 7.34 and 7.00% of the total cost were spent on weeding, harvesting, and tillage, respectively. Also, ₦16333.33, ₦14533.33,₦11800.00 and ₦11458.67 which accounted for 5.58, 4.09, 4.03 and 3.91% of the total cost were spent on land clearing, staking, mulching and transportation, respectively, as shown in Figure 40.

In a medium yam farms, amount spent on harvesting, weeding and tillage were ₦22666.67, ₦20666.67, ₦19500.00 which accounted 7.22, 7.19 and 6.81%of the total cost of production, respectively. Also, amount spent on land clearing, transportation, staking and mulching were ₦15833.33,₦14810.86,₦14483.33 and ₦11466.66 which accounted for 5.35, 5.17, 5.03 and 4.00% of the total cost of production, respectively, as shown in Figure 41.

In large farms, harvesting, weeding and tillage consumed ₦20066.67, ₦19566.67 and ₦19414.00 which accounted for 7.04, 6.86 and 6.81% of the total cost of producing yam on large farms, respectively. Also, about₦16435.10, ₦15666.67, 33₦13833.33 and ₦12233.33 and which accounted for 5.76, 5.49, 4.85, and 4.29% of the total cost of production were spent on transportation, land clearing, staking and mulching, respectively, in large yam farms as shown in Figure 42.

Table 32: Cost of Energy Consumed for Yam Cultivation (₦/ha)

				Cost Input (₦)					
Unit Operation	**Small farms**			**Medium farms**			**Large farms**		
	Farm 1	**Farm 2**	**Farm 3**	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 1**	**Farm 2**	**Farm 3**
Land clearing									
Manual energy	16500.00	16000.00	16500.00	16000.00	15500.00	16000.00	15000.00	15500.00	16500.00
Tillage									
Manual energy	21500.00	20000.00	20000.00	19000.00	20000.00	19500.00	19250.00	19500.00	19500.00
Planting									
Manual energy	12500.00	13400.00	12350.00	12350.00	12500.00	12400.00	12500.00	11900.00	12750.00
Biological energy	124000.00	132500.00	124500.00	126500.00	127500.00	121000.00	124000.00	124500.00	125500.00
Mulching									
Manual energy	11250.00	12000.00	12150.00	11100.00	11300.00	12000.00	12600.00	12450.00	11650.00
Staking									
Manual energy	14750.00	14350.00	14500.00	14250.00	14600.00	14600.00	14000.00	13500.00	14000.00
Fertilizer application									
Manual energy	8500.00	8500.00	8500.00	7600.00	7080.00	8000.00	7250.00	7370.00	7600.00
Chemical Energy N	21570.00	21570.00	21570.00	19413.00	19413.00	19413.00	19413.00	19413.00	19413.00
P_2O_5	2882.00	2882.00	2882.00	2785.90	2785.90	2785.90	2561.00	2561.00	2561.00
K_2O	1701.00	1701.00	1701.00	1512.00	1512.00	1512.00	1323.00	1323.00	1323.00
Weeding									
Manual energy	18250.00	18500.00	18250.00	17500.00	17000.00	17250.00	16000.00	16000.00	17500.00
Chemical energy (Herbicide)	3500.00	3200.00	3500.00	3200.00	3000.00	3100.00	2800.00	2800.00	3000.00
Mechanical energy	500.00	200.00	250.00	200.00	250.00	200.00	200.00	200.00	200.00
Harvesting									
Manual energy	21000.00	22000.00	21500.00	21000.00	20500.00	20500.00	20500.00	19500.00	20200.00
Transportation									
Manual energy	7750.00	7250.00	7800.00	8250.00	9000.00	9000.00	9000.00	9250.00	9250.00
Fuel energy	960.00	796.00	820.00	1033.00	1116.60	1033.00	1096.00	1096.00	1113.30
Mechanical energy	3000.00	3000.00	3000.00	5000.00	6000.00	4000.00	6000.00	6500.00	6000.00
Cost Input (₦ /ha)	290113.00	297849.00	289773.00	286693.90	289057.50	282293.90	283493.00	283363.00	288060.3
Yield (Kg)	11700.00	11300.00	12070.00	11150.00	12029.00	12620.00	12430.00	12300.00	11709.00
Cost Output (₦ /ha)	643500.00	621500.00	663850.00	613250.00	661595.00	694100.00	683650.00	676500.00	643995.00

Table 33: Average Cost of Input and Output in Yam Cultivation (₦ / ha)

	Cost Input (₦/ha)		
Unit Operation	**Small farms**	**Medium farms**	**Large farms**
Land clearing			
Manual energy	16333.33	15833.33	15666.67
Tillage			
Manual energy	20500.00	19500.00	19416.67
Planting			
Manual energy	12750.00	12416.67	12383.33
Biological energy	127000.00	125000.00	124666.70
Mulching			
Manual energy	11800.00	11466.67	12233.33
Staking			
Manual energy	14533.33	14483.33	13833.33
Fertilizer application			
Manual energy	8500.00	7560.00	7406.67
Chemical energy N	21570.00	19413.00	19413.00
P_2O_5	2882.00	2785.90	2561.00
K_2O	1701.00	1512.00	1323.00
Weeding			
Manual energy	18333.33	17250.00	16500.00
Chemical energy (Herbicide)	3400.00	3100.00	2866.667
Mechanical energy	316.67	216.67	200.00
Harvesting			
Manual energy	21500.00	20666.67	20066.67
Transportation			
Manual energy	7600.00	8750.00	9166.67
Thermal energy	858.67	1060.87	1101.76
Mechanical energy	3000.00	5000.00	6166.67
Cost Input (₦/ha)	292578.30	286015.10	284972.10
Yield (kg/ha)	11734.17	11991.50	12181.50
Cost Output (₦ /ha)	645379.00	659533.00	669983.00

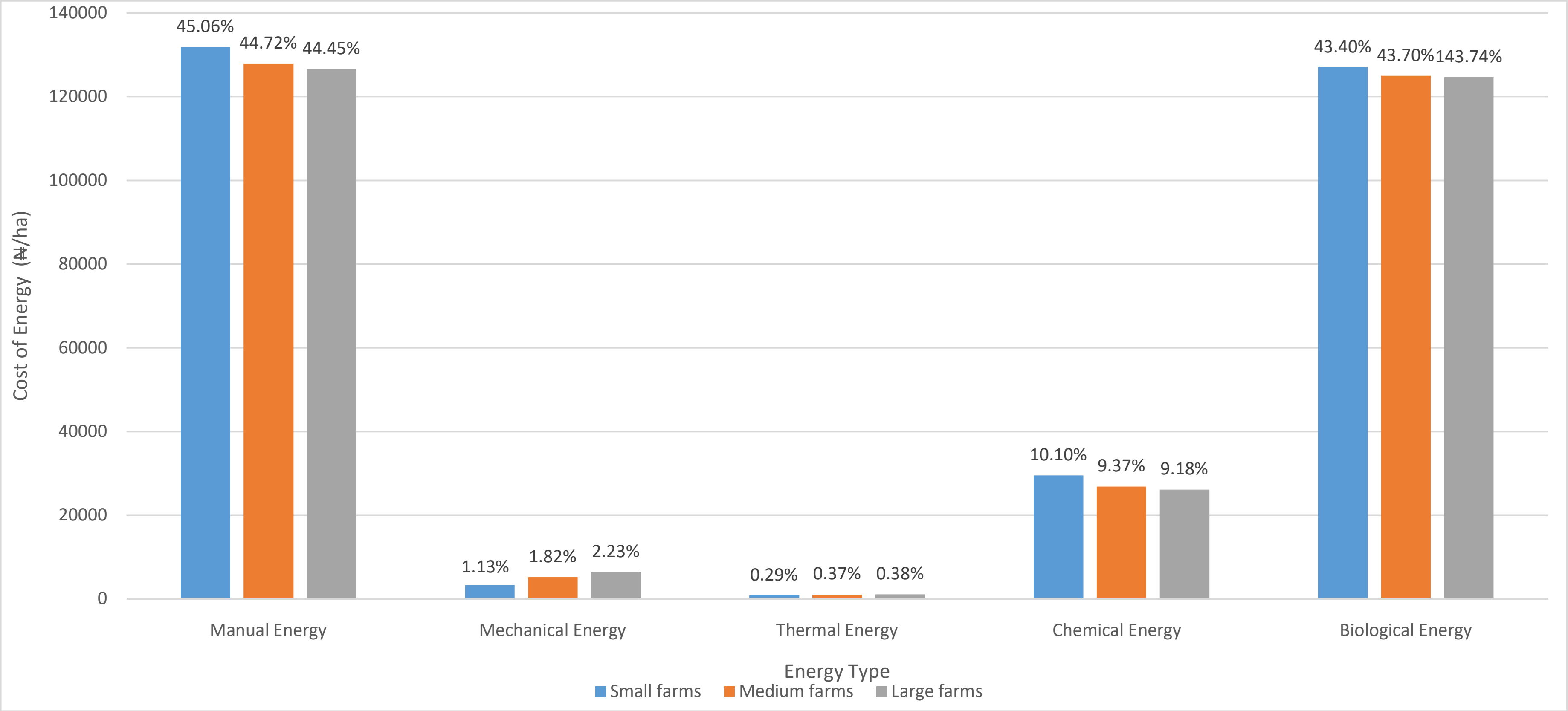


Figure 40: Cost of Energy Pattern for Yam Cultivation per hectare

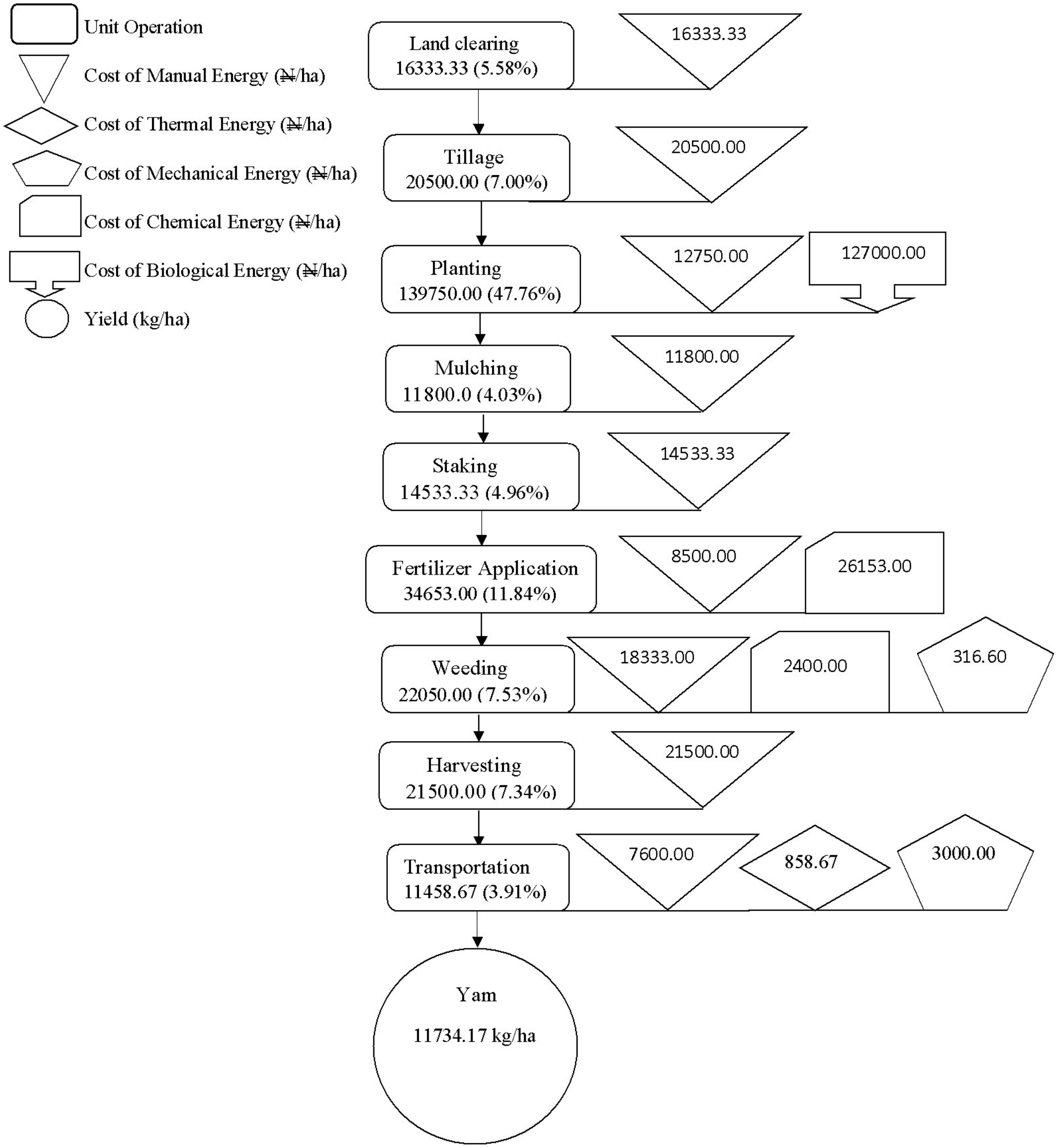


Figure41:EconomicFlowDiagraminaSmall Yam Farm

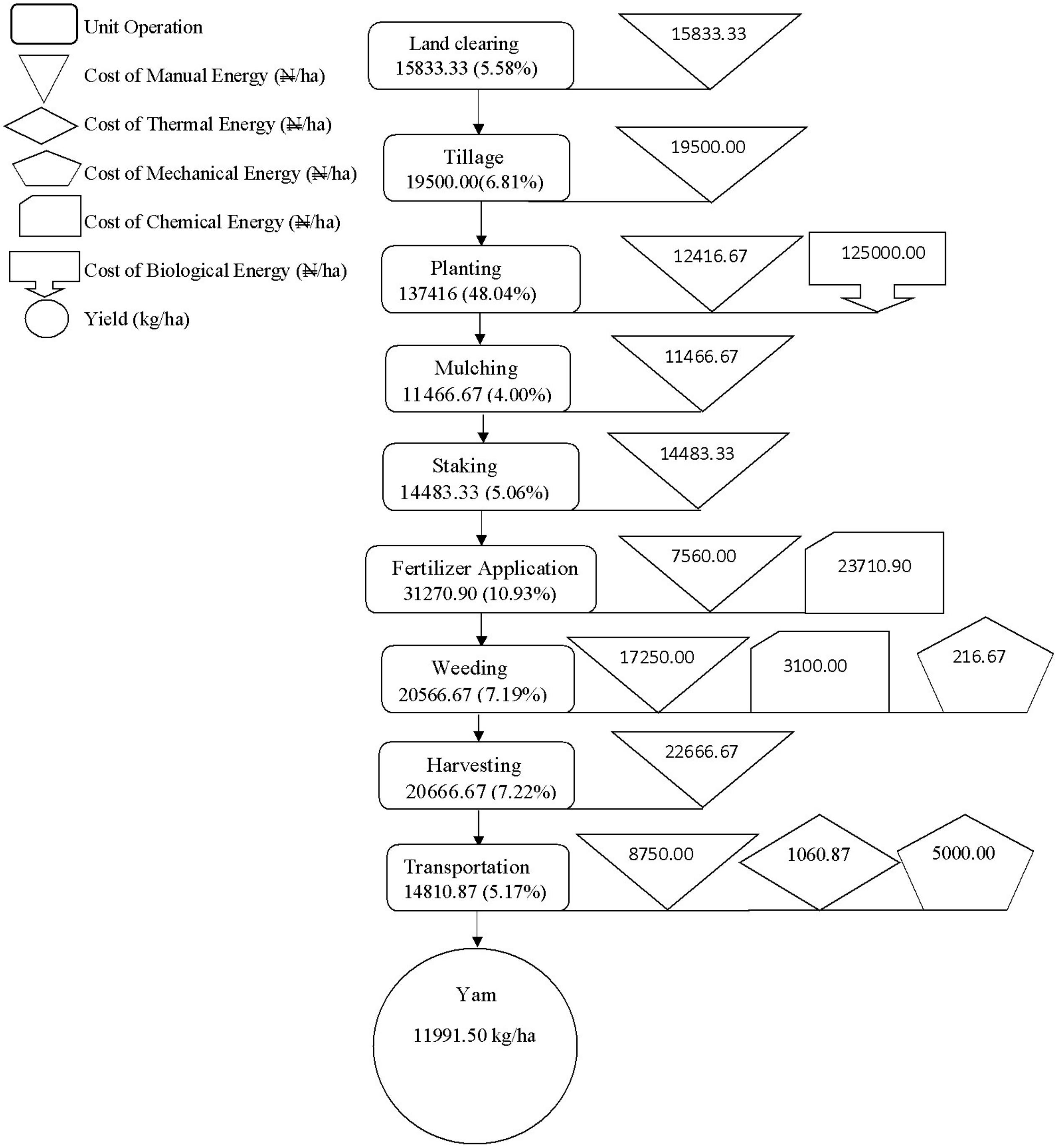


Figure 42:EconomicFlowDiagraminaMedium Yam Farm

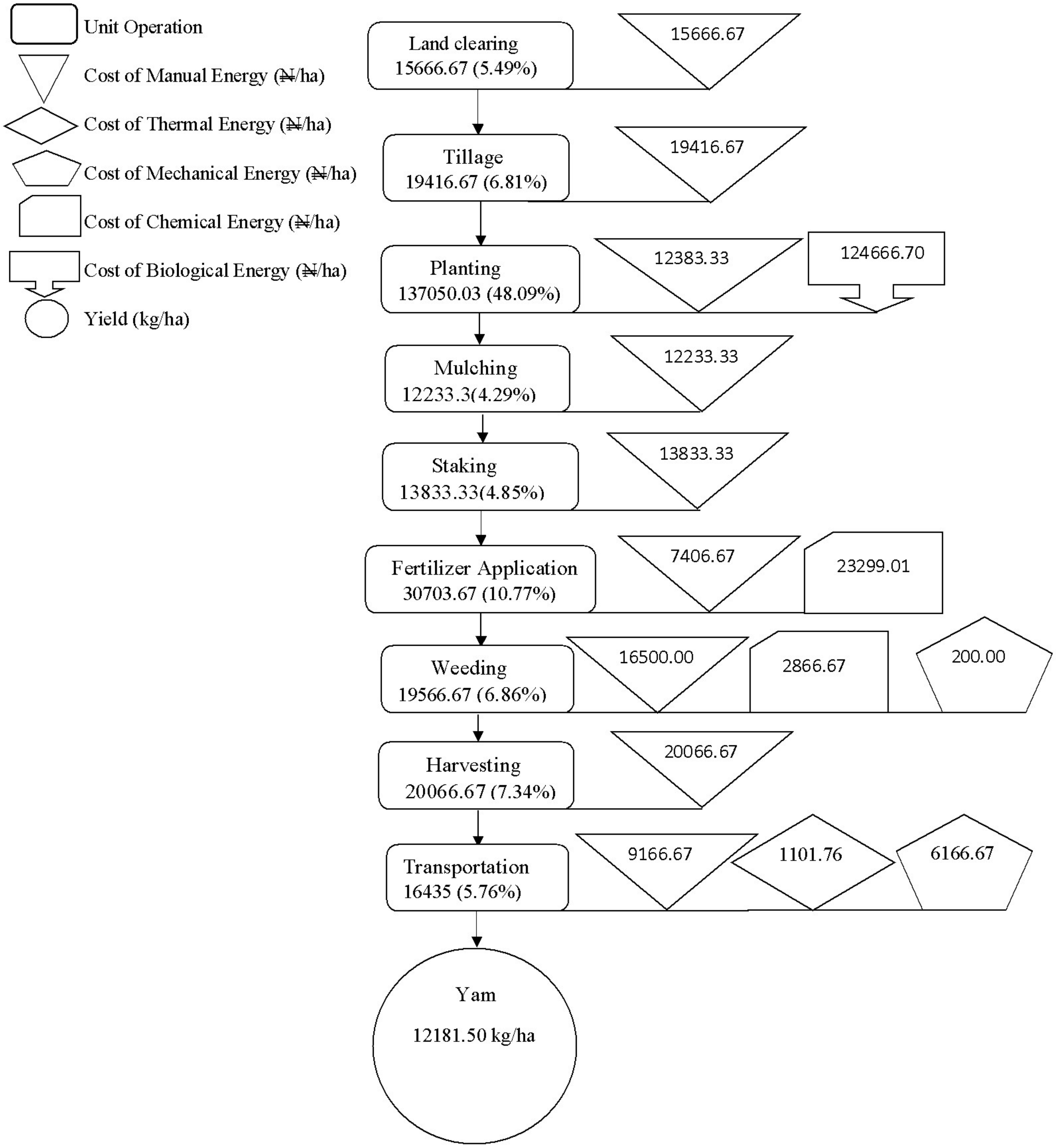
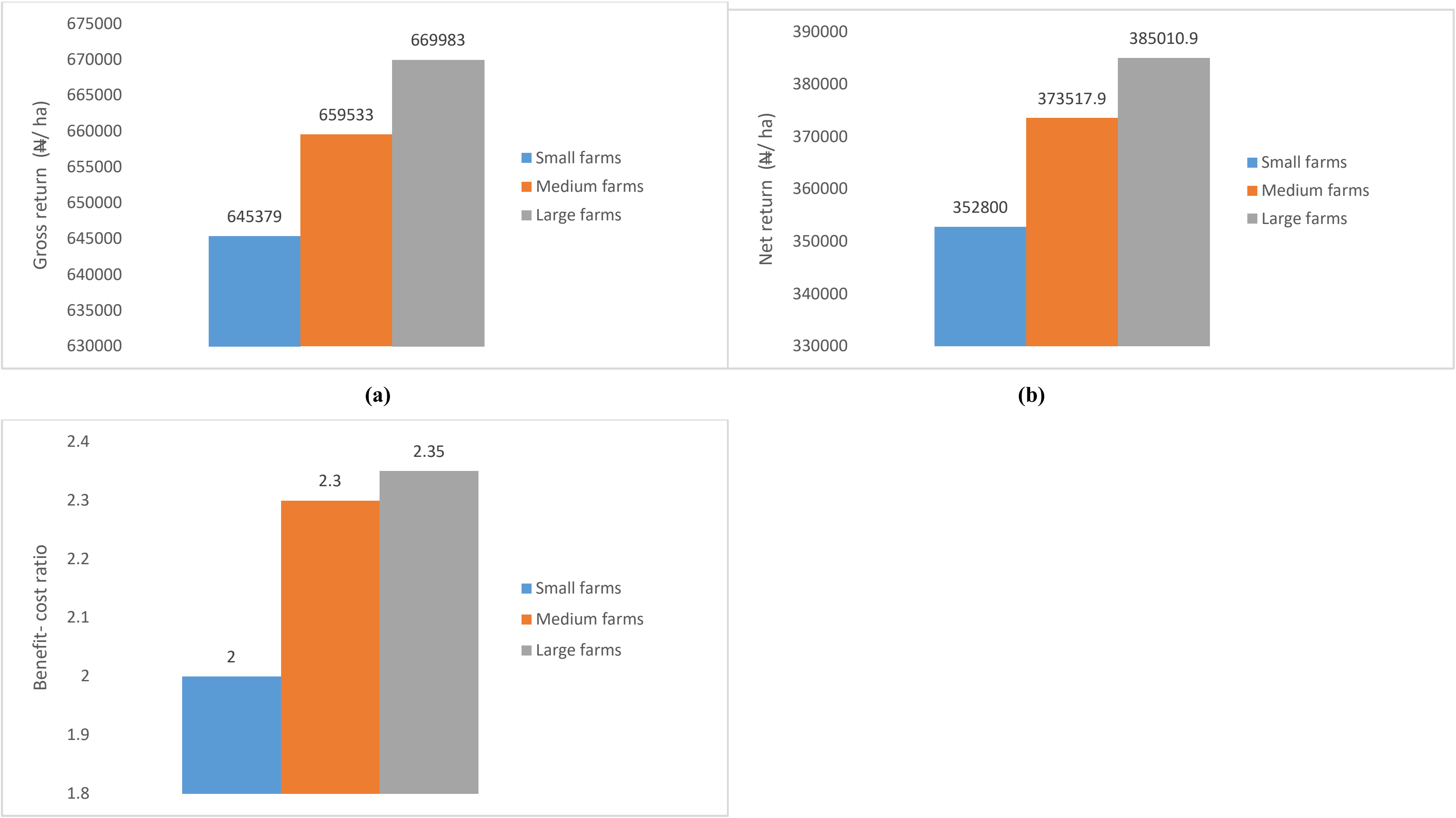


Figure 43:EconomicFlowDiagraminaLarge Yam Farm

4.11. 2 Economic indicator of Yam Cultivation

The gross return in small, medium and large yam farms were ₦645379.00, ₦659533.00 and ₦699983.00, respectively, as shown in Figure 44 (a). The net return per hectare in small, medium and large farms were ₦352800.7, ₦373517.9 and ₦385010.9, respectively, as shown in Figure 44 (b).Statistical inference shows that there is significant difference in net return per hectare due increase in scale of production from small to medium and large farms.There was an increase in the net return from small to large farms, indicating that more gain can be obtained in medium and large farms respectively. The net return obtained was closerto ₦326349.00 obtained in Nasarawa, Nigeria from yam per hectare (Jonathan and Anthony, 2012).

Benefit cost ratio in small, medium and large farms were 2.20, 2.30 and 2.35, respectively, as shown in Figure 44 (c). This indicated that return per naira invested were ₦2.00, ₦2.30 and ₦2.35. Since the benefit cost ratio is greater than 1.0, these indicated that from economic stand point, yam production can be said to be profitable. The cost- benefit ratio reported by Zaknayiba and Tanko(2013) was 2.19. Their cost- benefit ratio was lower than that obtained for this study. This was because farmers in Karu Local Government Area, Nasarawa State, Nigeria where the survey was carried out faced some challenges, which included lack of access to inputs, high cost of inputs and poor transportation facilities.Furthermore, this study further supports the findings of Adekayode (2004); Eyitayo *et al.* (2010); Izekor and Olumeze (2010); and Ibitoye and Onimisi (2013) who stated that yam production is a profitable enterprise in the previous studies conducted in South Western Nigeria, Edo, Taraba and Kogi States of Nigeria respectively. The cost-benefit ratio increased from small to large farms. This indicates that more profit can be made when yam is produced in large scale.



(a) **(b)**

(c)

Figure 44: Economic Indicators for Yam Cultivation per hectare: Gross Return (a), Net Return (b), Benefit –Cost Ratio (c)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions were drawn from the results acquired in this study:

1. The total energy input for rice production varied from 143962.62 – 15107.39MJ/ha and the corresponding values for maize and yam production were 9445.94 – 10084.55MJ/ha and 19020.37 – 19835.08 MJ/ha, respectively. The output energy for rice production varied from 94815.00 - 11310.30MJ/ha, and the corresponding values for maize and yam production were 41062.00 – 50004.34 MJ/ha and 57131.17 - 60298.42 MJ/ha respectively
2. Energy productivity values for rice production varied from 0.44 - 0.50 kg/MJ and the corresponding values for maize and yam production were 0.27 - 0.36 kg/MJ and 0.59 - 0.64 kg/MJ respectively.
3. Energy use efficiency for rice production varied from 6.41 to 7.51 and the corresponding energy efficiency for maize and yam were 4.07- 5.29 and 2.88 to 3.17, respectively, indicating that energy were efficiently used generally in all the farms.
4. Rice, maize and yam production mainly depend on non-renewable and indirect energy input especially fertilizer (chemical energy) and fuel (thermal energy).
5. The total expenditure for rice cultivation varied from ₦109382.60 – ₦103383.00 and the corresponding values for maize and yam were ₦73363.66 – 81520.56 and 284974.10 – 286015.10, respectively. The cost benefit ratio for rice production varied from 2.41 – 2.84 and the corresponding values for maize and yam were 1.75 – 2.31 and 2.00 – 2.35, respectively, indicating that rice, maize and yam production were profitable from economic standpoint.
6. The developed models on pattern of energy utilization are:$\ln y_i = 0.02lnx_1 + 0.05lnx_2 + 0.08lnx_3 + 0.13lnx_4 + 0.86x_5 + 0.44lnx_6 - 0.64lnx_7 + 0.003lnx_8$ ($R^2 = 0.98$) (rice),$\ln y_i = 0.59lnx_1 - 2.15lnx_2 + 6.72lnx_3 - 0.84lnx_4 - 2.50\ln x_5 + 0.17lnx_6 + 0.12lnx_7 + 0.057lnx_8R^2 = 0.98$ (maize) and $\ln y_i = -0.15lnx_1 + 0.08lnx_2 + 0.15lnx_3 + 0.16lnx_4 + 0.03lnx_5 + 0.60lnx_6 - 0.11lnx_7 + 0.60lnx_8$ ($R^2 = 0.98$) (yam). The models were capable of predicting energy output at different energy inputs beyond the two seasons considered in this work.

5.2 Recommendations

In Nigeria, like any other developing countries there is scarcity of data on energy expenditure on crop production. Hence, other crops that the scope of this work does not cover should be investigated.Estimation of national energy consumption for different agricultural production and comparing results from other countries would be helpful for the adoption of different farming systems globally. Additionally, this comparison can find the most important barriers to reduce energy use on farms in each country and globally.

Utilization of alternative sources of energy such as organic fertilizers, farmyard manure may be suggested to reduce the environmental footprints of energy inputs and to obtain sustainable food Production systems.It is suggested that some specific policies should be taken to reduce the negative effects of energy use, such as pollution, global warming and nutrient loading.

Also, the cost of producing rice, maize and yam could be reduced by using alternative energy resources to replace chemical energy (fertilizer) and thermal energy (fossil fuel) used for rice and maize production. While, the use of biological (yam sett) and chemical energy resources (fertilizer) should be reduced in yam production. More accurate fertilizer use management according to soil test and plant requirement as well as more application of manures and other natural sources for fertilizing the soil are among suggestions to improve the energy use efficiency without impairing yield and profitability.

Choosing and using matched tractors and equipment and selecting the right operation at the right time can reduce the direct use of diesel and petrol; better equipment and reduction of tractor passes on farms can significantly reduce fuel consumption, farm expenditure, and soil compaction. The effect of more powerful tractors and larger equipment on fuel and energy consumption should be investigated in the future. New tractors and machinery are more energy efficient; however, they needed more energy to produce, service, and maintain.

The method of operation must be studied further and guidance must be given to managerial staff. Furthermore, farmers have to learn that the use of several operations, for example, in soil preparation, increases fuel consumption and has adverse environmental impacts, such as erosion and soil compaction. Using new farming equipment and methods would reduce fuel consumption and environmental impacts considerably.

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APPENDIX 1

Appendix 1a: Energy Input and Output in the Production of Rice (MJ)

	Energy Input (MJ)								
Unit Operation	**Small farms**			**Medium farms**			**Large farms**		
	Farm 1	**Farm 2**	**Farm**	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 1**	**Farm 2**	**Farm 3**
Land clearing									
Manual energy	96.21	97.005	128.24	514.4	450.73	512.96	776.04	901.74	901.74
Tillage									
Manual energy	29.04	31.23	43.2	155.36	135.52	158.56	235.2	277.9	351
Mechanical energy	1048.2	1051.5	1396.68	5103.76	3685.92	5041.76	8146.44	8810.2	11424.06
Thermal energy	2348.25	2400.51	3214.68	12520	9627.8	10620	15070.32	22502.76	24246
Planting									
Manual energy	9.315	9.63	12.58	53.12	49.00	52.48	79.08	93.52	119.7
Biological energy	1472.475	1310.475	1986.5	6605.6	7139.44	7562	9609.6	14277.2	17577.9
Transplanting									
Manual energy	65.25	67.35	94.5	350.24	293.44	344.56	480	583.8	721.62
Fertilizer application									
Manual energy	28.725	28.44	38.72	155.2	134.12	144.16	227.16	227.78	342
Chemical energy N	14526.6	14760.9	19525	78100	69430.9	76225.6	116212.8	137768.4	171507.6
P_2O_5	766.725	717.75	1042.6	4168	3252.2	4426.4	6264	5895.4	8613
K_2O	618.225	585	853.8	3288	2560.6	3370.16	4932	5562.2	7151.4
Weeding									
Manual energy	96.60	95.92	129.86	515.76	450.8	511.6	779.16	902.58	1152.72
Chemical energy (Herbicide)	432.00	357.6	478.4	1987.2	2007.6	2337.6	2920.8	3208.8	5434.2
Mechanical energy	389.7	385.5	728.5	3046.4	1799	2056	4371	5099.5	4626
Harvesting									
Manual energy	89.625	90.855	124.66	480.16	423.64	488.88	719.04	843.08	1080
Threshing									
Manual energy	38.49	39.03	50.9	200.88	182.14	203.6	301.32	353.36	452.88
Transportation									
Manual energy	34.5	33.45	44.62	173.84	164.43	173.68	259.2	323.68	388.26
Thermal energy	364.5	339	455	1992	1736	1992	3306.72	3848.6	4903.2
Mechanical energy	122.955	120.375	165	770	643.79	770	1231.8	1496.46	1859.4
Energy Input (MJ)	22576.65	22521.53	30513.44	120180	104167.1	116992.1	175921.8	212977	263110.5
Yield (Kg)	9412.5	9825	13920	56000	48020	58576	86400	104300	133956
Energy Output (MJ)	138363.8	144427.5	204624	823200	705894	861064	1270080	1533210	1969153

Appendix 1b: Estimates of energy consumed (MJ) for various rice processing operations.

	Energy Input (MJ)								
Unit Operation	**Small mills**			**Medium mills**			**Large mills**		
Energy Input (MJ)	**Mill 1**	**Mill 2**	**Mill 3**	**Mill 1**	**Mill 2**	**Mill 3**	**Mill 1**	**Mill 2**	**Mill 3**
Pre- cleaning									
Electrical energy	10.344	11.9	11.043	25.86	23.68	23.74	31.5	28.55	29.375
Manual energy	0.928	0.89	1.008						
Parboiling									
Electrical energy				106.88	104.92	107.12	130.875	129.7	128.65
Thermal energy	143.44	167	166.59						
Manual energy	1.016	1.22	1.215	2.52	2.46	2.4	3.00	3.15	3.05
Drying									
Electrical energy			57.726	117.32	106.46	105.9	134.625	134.15	137.65
Manual energy	14.368	16.2	1.08	2.28	2.42	2.26	2.775	3.2625	2.8875
Milling									
Thermal energy	171.64	205.06	180.549	363.67	372.76	351	453.25	448.125	442.125
Manual energy	0.728	0.85	0.837	1.8	1.7	1.68	2	2.175	1.85
Sorting									
Electrical energy	7.52	10.01	8.883	17.48	18.14	18	24.3	20.475	22.75
Manual energy	1.088	1.325	1.2375	2.73	2.71	2.74	3.425	3.275	3.1875
De-stoning									
Electrical energy			57.744	14.6	14.6	14.22	18.8125	18.3125	18.5
Manual energy			1.629	3.00	3.18	3.08	3.2	3.00	3.9
Packaging									
Electrical energy			0.585	1.28	1.25	1.28	1.6125	1.6125	1.6125
Manual energy	1.72	2.05	0.4905	1.07	1.13	1.24	1.3	1.425	1.40
Total energy use	352.792	416.5	490.617	660.4	655.4	634.66	810.675	797.2	796.925
Yield (kg)	490	615	553.95	1270	1270	1275	1601.75	1618.75	1661.25

Appendix 1c: Cost Input and Output in the Production of Rice (₦)

Unit Operation	Cost Input (₦) Small farms			Medium farms			Large farms		
	Farm 1	Farm 2	Farm 3	Farm 1	Farm 2	Farm 3	Farm 1	Farm 2	Farm 3
Land clearing									
Manual energy	21975	21750	29300	116000	99750	114000	168000	199500	199500
Tillage									
Manual energy	9750	9900	13000	51200	44800	51200	76800	89600	111600
Mechanical energy	1875	1875	2500	10000	8750	10000	14400	16800	22500
Thermal energy	6000	5850	7900	30320	26792.5	30320	45360	52990	65970
Planting									
Manual energy	1650	1800	2400	8000	7000	8000	12000	15400	18000
Biological energy	3975	3900	5000	21200	18900	22000	30000	31500	45000
Transplanting									
Manual energy	9750	9000	12500	58000	50750	58000	84000	94500	126000
Fertilizer application									
Manual energy	2250	2100	3000	11200	10500	11200	14400	18200	23400
Chemical energy N	19200	19500	25600	104000	84000	100800	144000	168000	219600
P_2O_5	9900	9000	13200	48000	46200	48000	72000	84000	108000
K_2O	9900	9000	13200	48000	46200	48000	72000	84000	108000
Weeding									
Manual energy	22125	21000	30500	116000	98000	118000	156000	185500	234000
Chemical energy (Herbicide)	5400	5550	6800	28000	23800	27200	43200	50400	64800
Mechanical energy	450	525	650	2600	2450	2800	3900	4200	5850
Harvesting									
Manual energy	21000	21375	28000	116000	99750	110000	159000	189000	238500
Threshing									
Manual energy	12375	12375	16000	60000	49000	56000	84000	98000	130500
Transportation									
Manual energy	4350	4350	5600	22000	19950	22800	31200	35700	45000
Thermal energy	682.5	673.5	854	6120	5110	6120	7800	9016	12150
Mechanicalenergy	2700	2850	3400	13600	11900	13600	19200	22400	28800
Cost Input (₦)	165307.5	162373.5	219404	870240	753602.5	858040	1237260	1448706	1864170
Yield (kg)	9750	9825	13920	56000	48020	58576	86400	104300	133956
Cost Output (₦)	376500	393000	556800	2240000	1920800	2343040	3456000	4172000	5358240

Appendix 1d: Cost of energy consumed (₦) for various paddy processing operations in the three mills

	Cost Input (₦)								
Unit Operation	Small mill			Medium mill			Large mill		
	Mill 1	Mill 2	Mill 3	Mill 1	Mill 2	Mill 3	Mill 1	Mill 2	Mill 3
Pre- cleaning									
Electrical energy	153.10	152.15	149.15	151.6	140.0	140.0	140.0	124.3	145.0
Manual energy	600.00	600.00	600.00	-	-	-	-	-	-
Parboiling									
Electrical energy	-	-	-	340.0	336.5	340.0	327.0	321.0	320.0
Thermal energy	1000.00	1000.00	900.00	-	-	-	-	-	-
Manual energy	2200.00	2200.00	2200.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
Drying									
Electrical energy				378.00	360.00	370.0	370.00	375.00	372.00
Manual energy	1500.0	1500.0	1500.0	800.0	800.0	800.0	800.0	800.0	800.0
Milling									
Thermal energy	1285.0.0	1316.0.0	1271	1087.1	1078.55	1076.72	951.35	1029.35	971.5
Manual energy	2000.00	2000.00	2000.00	2000.00	2000.0	2000.0	2000.0	2000.0	2000.00
Sorting									
Electrical energy	57.28	57.00	56.90	57.90	57.10	57.05	57.00	57.00	57.10
Manual energy	1200.00	1200.00	1200.0	1200.00	1200.0	1200.00	1200.00	1000.00	1000.0
De-stoning									
Electrical energy	---	---	57.00	57.28	57.05	57.00	57.00	57.00	58.70
Manual energy	---	---	1200.00	1200.00	1200.00	1200.00	1000.00	1000.00	1100.00
Packaging									
Electrical energy	---	---	29.00	30.00	28.00	30.00	30.00	29.00	28.00
Manual energy	1000.00	1000.00	1000.00	1000.0	1000.00	1000.0	1000.00	1000.0	1000
Cost of energy input (₦)	10995.38	11025.15	12163.05	10301.88	10257.2	10270.77	9932.35	9792.65	9852.3
Yield (kg)	612.5	615	615.5	621	627.5	620	651	645	652

Appendix 1e: Energy Input and Output in the Production of Maize (MJ)

Unit Operation	Energy Input (MJ)								
	Small farms			Medium farms			Large farms		
	Farm 1	Farm 2	Farm 3	Farm 1	Farm 2	Farm 3	Farm 1	Farm 2	Farm 3
Land clearing									
Manual energy	1.095	1.17	0.988	5.94	4.69	6.16	12.6	9.3	9.455
Mechanicalenergy	259.5	262.8	233.35	1467.27	1141	1280	3040	2280	2356
Thermalenergy	2175.75	2234.1	1883.83	10130.4	8093.4	10469.6	21620	16485	16833
Tillage									
Manual energy	1.005	0.945	0.884	6.03	5.46	5.68	13.00	9.60	10.23
Mechanical energy	247.5	243.3	209.3	1458.27	1123.5	1300	3240	2422.5	2526.965
Thermalenergy	2115.6	2102.4	1931.28	10774.8	8730.4	10088	20880	16132.5	16716.75
Planting									
Manual energy	25.05	25.125	22.165	6.3	5.25	6.16	14.0	12.15	11.315
Mechanicalenergy	-	-	-	1437.75	1169	1300	2990	2200.5	2216.5
Thermal energy	-	-	-	2388.6	1847.3	2108	5200	3954	4061
Biological energy	579.75	573.45	501.8	3571.2	2681	2822.4	7116	5370	5401.75
Fertilizer application									
Manual energy	17.475	17.715	15.119	98.01	70.91	86.4	213.6	161.4	168.175
Chemical energy N	5937.75	5922.75	5152.55	35838	27426	31816	72150	54202.5	56606
P_2O_5	526.5	531	447.85	3168	2439.5	2876	6900	5250	5324.25
K_2O	424.5	426	356.2	2110.5	1911	2280	4650	3495	3642.5
Weeding									
Manual energy	7.815	8.04	7.553	5.67	4.62	5.28	13.2	10.2	10.075
Chemical energy (Herbicide)	594	588.75	510.25	3528	2625	3160	7240	5565	5487
Mechanical energy	588.075	591.555	509.99	2585.52	2011.59	2304	5505.6	4109.55	4247
Thermal energy				640.575	517.44	587.52	1364.4	1053.45	1085.775
Harvesting									
Manual energy	48.00	48.06	41.613	272.16	222.67	234.8	620.0	453.0	479.26
Threshing									
Manual energy	4.14	4.26	3.588	25.02	19.46	22.08	56.00	39.75	42.005
Mechanical energy	231.405	239.625	195.052	1165.05	956.06	1055.6	2544.4	1935	1909.29
Thermal energy	582.6	580.8	499.98	3028.5	2357.46	2693.6	6768	5068.5	5239
Transportation							0	0	0
Manual energy	3.945	3.975	3.419	25.65	19.845	24.56	70.0	53.85	55.025
Thermal energy	514.5	529.5	453.7	3951	3097.15	3550.16	11360	8655	8959
Mechanical energy	194.1	193.95	167.7	1330.2	1050	1200	4260	3277.5	3317
Energy Input (MJ)	15080.06	15129.27	12980.46	89018.37	69529.67	81282	187840.8	142205.3	146404.3
Yield (kg)	4095	4125	3770	30645	23541	26776	66700	52695	52033.5
Energy Output (MJ)	60196.5	60637.5	55419	450481.5	346052.7	393607.2	980480	774616.5	764892.5

Appendix 1f: Cost Input and Output for Maize Cultivation per Hectare (₦)

	Cost Input (₦)								
Unit Operation	**Small farms**			**Medium farms**			**Large farms**		
	Farm 1	**Farm 2**	**Farm 3**	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 1**	**Farm 2**	**Farm 3**
Land clearing									
Human energy	2400	2400	1950	13500	9800	11200	28000	19500	20150
Machinery energy	3600	3750	3250	22500	16800	19200	42000	33000	32550
Thermal energy	6600	6600	5720	38700	29400	34400	80000	61500	65100
Tillage									
Human energy	2400	2400	2080	13500	11200	12800	32000	22500	21700
Machinery energy	4500	4200	3640	22500	17500	20800	46000	36000	37200
Thermal energy	6750	6600	5720	38700	28000	32800	82000	61500	62000
Planting									
Human energy	9750	9750	8450	12600	11200	12000	28000	19500	20150
Machineryenergy				27000	17500	20000	50000	37500	37200
Thermal energy				9900	7700	8000	17000	13500	15500
Biological energy	1425	1500	1300	8550	6650	7200	19000	13500	13175
Fertilizer application									
Human energy	10500	9750	9100	58500	45500	52000	130000	97500	93000
Chemical energy N	16500	17850	14365	98100	70700	81600	184000	135000	156550
P_2O_5	8250	8400	7371	50283	38709.3	44720	108600	82200	83002.5
K_2O	6668.85	6668.85	7020	39600	31121.3	35920	83160	65220	66650
Weeding									
Human energy	9750	9000	8450	36000	31500	32000	80000	60000	65100
Chemical energy (Herbicide)	3750	3450	3380	20700	15750	18000	48000	31500	34100
Machinery energy	300	375	325	18000	17500	20000	46000	36000	32550
Thermal energy				2160	1750	2000	5000	3600	3565
Harvesting									
Human energy	12000	12300	10400	67500	56000	64000	151000	105000	108500
Threshing									
Human energy	1200	1275	1040	6750	5250	5600	15000	11250	11625
Machinery energy	5250	5250	3900	22500	17500	20000	40000	30000	38750
Thermal energy	900	975	780	4950	3850	4800	10000	7500	8525
Transportation									
Human energy	3000	3000	2600	31500	24500	32000	70000	45000	54250
Thermal\ energy	1200	1275	1105	13500	9450	11200	34000	22500	26350
Machinery	4500	6000	4550	31500	21000	24000	70000	30000	31000
Cost Input (₦)	121193.9	122768.9	106496	708993	545830.6	605440	1498760	1080270	1138243
Yield (kg)	4245	4125	3510	31995	24591	25656	69700	52695	52033.5
Cost Output (₦)	212250	206250	202475	1599750	1229550	1282800	3485000	2634750	2601675

Appendix 1g: Energy Input and Output in the Production of Yam (MJ)

	Energy Input (MJ)								
Unit Operation	**Small farms**			**Medium farms**			**Large farms**		
	Farm 1	**Farm 2**	**Farm 3**	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 1**	**Farm 2**	**Farm 3**
Land clearing									
Manual energy	81.175	72.0	85.05	276.12	276.18	376	489.5	616.0	489.06
Tillage									
Manual energy	109.616	98.325	116.856	388.8	379.32	519.2	686.95	877.94	692.45
Planting									
Manual energy	35.819	31.455	37.116	118.38	118.38	158.8	211.2	267.4	209.44
Biological energy	16586.9	14550	17460	55242	56040	76800	100760	127106	100727
Mulching									
Manual energy	9.265	8.145	9.99	31.8	31.8	42.8	60.5	71.68	57.2
Staking									
Manual energy	76.5	64.125	81.0	260.46	259.2	344.88	473.0	616.0	488.95
Fertilizer application									
Manual energy	22.083	21	29.736	89.4	84.0	112.0	152.9	203.0	145.42
Chemical energy N	12289.3	10843.5	13012.2	42660	42660	56800	77319	98406	77319
P_2O_5	1774.8	1566	1879.2	6264	6264	8352	11101.2	14128.8	11101.2
K_2O	1048.05	924.75	1109.7	3288	3288	4384	5274.5	6713	5274.5
Weeding									
Manual energy	42.738	37.605	44.604	144	149.4	199.2	273.9	349.3	273.9
Chemical energy (Herbicide)	547.4	492	579.6	1872	1872	2512	3344	4256	3454
Mechanical energy	647.36	430.5	691.65	2164.8	1542	2056	3786.75	4819.5	2717
Harvesting									
Manual energy	95.99	84.61	102.06	324.0	329.4	445.2	579.81	727.44	569.8
Transportation									
Manual energy	38.148	35.16	42.48	129.6	116.64	164.8	214.5	272.16	215.6
Thermal energy	422.875	355.5	447.3	1864.2	2010	2485.6	3654.2	4617.2	3680.6
Mechanical energy	72.726	53.475	64.17	577.5	551.82	770	1569.15	1916.46	1466.3
Energy Input (MJ)	33900.75	29668.16	35703.14	115695.1	115972.1	156522.5	209951.1	265849.1	209268.1
Yield (kg)	19720	18112.5	21753	69900	72687	97680	130240	176400	133149.5
Energy Output (MJ)	97614	83345.25	107677.4	346005	359800.5	472626	644688	873180	659089.8

Appendix 1h: Cost of Energy Consumed for Yam Cultivation (₦)

	Cost Input (₦)								
Unit Operation	**Small farms**			**Medium farms**			**Large farms**		
	Farm 1	**Farm 2**	**Farm 3**	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 1**	**Farm 2**	**Farm 3**
Land clearing									
Manual energy	28050	24000	29700	96000	93000	128000	165000	217000	181500
Tillage									
Manual energy	36550	30000	36000	114000	120000	156000	211750	273000	214500
Planting									
Manual energy	21250	20100	22230	74100	75000	99200	137500	166600	140250
Biological energy	210800	198750	224100	759000	765000	968000	1364000	1743000	1380500
Mulching									
Manual energy	19125	18000	21870	66600	67800	96000	138600	174300	128150
Staking									
Manual energy	25075	21525	26100	85500	87600	116800	154000	189000	154000
Fertilizer application									
Manual energy	14450	12750	15300	45600	42480	64000	79750	103180	83600
Chemical Energy N	36669	32355	38826	116478	116478	155304	213543	271782	213543
P_2O_5	4899.4	4323	5187.6	16715.4	16715.4	22287.2	28171	35854	28171
K_2O	2891.7	2551.5	3061.8	9072	9072	12096	14553	18522	14553
Weeding									
Manual energy	31025	27750	32850	105000	102000	138000	176000	224000	192500
Chemical energy (Herbicide)	5950	4800	6300	19200	18000	24800	30800	39200	33000
Mechanical energy	850	300	450	1200	1500	1600	2200	2800	2200
Harvesting									
Manual energy	35700	33000	38700	126000	123000	164000	225500	273000	222200
Transportation									
Manual energy	13175	10875	14040	49500	54000	72000	99000	129500	101750
Fuel energy	1632	1194	1476	6198	6699.6	8264	12056	15344	12246.3
Mechanical energy	5100	4500	5400	30000	36000	32000	66000	91000	66000
Cost Input (₦)	493192.1	446773.5	521591.4	1720163	1734345	2258351	3118423	3967082	3168663
Yield (kg)	19890	16950	21726	66900	72174	100960	136730	172200	128799
Cost Output (₦)	1093950	932250	1194930	3679500	3969570	5552800	7520150	9471000	7083945

Appendix 1i: Econometric Estimation Results of Rice Cultivation

Endogenous variable:	**Rice yield**		
Exogenous variables	Coefficients (α_1)	Std. error	P-value
$Model\ I: \ln Y_i = \alpha_1 lnX_1 + \alpha_2 lnX_2 + \alpha_3 lnX_3 + \alpha_4 lnX_4 + \alpha_5 lnX_5 + \alpha_6 lnX_6 + \alpha_7 lnX_7 + \alpha_8 lnX_8 + e_i$			
1. Manual Energy (X_1)	0.026848543	0.0832	0.00***
2. Thermal Energy (X_2)	0.050827226	0.0508	0.00***
3. Mechanical Energy (X_3)	0.081578344	0.0594	0.05*
4. Biological Energy (X_4)	0.138912823	0.1951	0.00***
5. Chemical Energy N (X_5)	0.861252373	0.2301	0.00***
6. Chemical Energy P_2O_5 (X_6)	0.446233535	0.3789	0.69
7. Chemical Energy K_2O (X_7)	-0.640411635	0.5719	0.25
8. Chemical Energy Herbicide(X_8)	0.003448601	0.0227	0.98
Return to Scale (RTS)	0.96869		
Durbin Watson Test (DW)	2.25054		
R-square	0.99		

***	Significance at 1% level
**	Significance at 5% level
*	Significance at 10% level

Appendix 1j: Econometric Estimation Results for Direct and Indirect Energy for Rice Cultivation.

Endogenous variable:	**Rice yield**		
Exogenous variables	Coefficients (β_1)	Std. error	P-value
	$Model\ II : \ln Y_i = \beta_1 lnDE + \beta_2 lnIDE + e_i$		
1. Direct Energy (DE)	0.0472623	0.0291	0.00***
2. Indirect Energy (IDE)	0.8994284	0.0225	0.00***
Return to Scale (RTS)	0.946691		
Durbin Watson Test (DW)	2.32009		
R-square	0.99		

*** Significance at 1% level

** Significance at 5% level

* Significance at 10% level

Appendix 1k: Econometric Estimation results of Rice Processing

Endogenous variable:	**Rice yield**		
Exogenous variables	Coefficients (α_1)	Std. error	P-value
$ModelIII : \ln Y_i = \alpha_1 lnX_1 + \alpha_2 lnX_2 + \alpha_3 lnX_3 + \alpha_4 lnX_4 + \alpha_5 lnX_5 + \alpha_6 lnX_6 + \alpha_7 lnX_7 + \alpha_8 lnX_8 + e_i$			
1. Electrical Energy (X_1)	0.6268821	0.1473	0.00***
2. Manual Energy (X_2)	0.8139404	0.2559	0.00***
3. Thermal Energy (X_3)	0.3491489	0.2319	0.15
Return to Scale (RTS)	1.789971		
Durbin Watson Test (DW)	2.8512861		
R-square	0.98		

*** Significance at 1% level

** Significance at 5% level

* Significance at 10% level

Appendix 1l: Econometric Estimation results for Direct and indirect Energy for rice Processing.

Endogenous variable:	**Rice yield**		
Exogenous variables	Coefficients (β_1)	Std. error	P-value
	$Model\ IV : \ln Y_i = \beta_1 lnDE + \beta_2 lnIDE + e_i$		
1. Direct Energy (DE)	0.1954153	0.0286	0.00
2. Indirect Energy (IDE)	1.0476865	0.0244	0.00
Return to Scale (RTS)	1.243102		
Durbin Watson Test (DW)	2.8512861		
R-square	0.98		

***	Significance at 1% level
**	Significance at 5% level
*	Significance at 10% level

Appendix 1m: Econometric Estimation Results for Maize Production.

Endogenous variable:	**Maize yield**		
Exogenous variables	Coefficients	Std. error	P-value
$Model\ V : \ln Y_i = \alpha_1 lnX_1 + \alpha_2 lnX_2 + \alpha_3 lnX_3 + \alpha_4 lnX_4 + \alpha_5 lnX_5 + \alpha_6 lnX_6 + \alpha_7 lnX_7 + \ \alpha_8 lnX_8 + e_i$			
1. Manual Energy (X_1)	0.59171268	0.1663	0.00***
2. Thermal Energy(X_2)	-2.14991743	0.9531	0.00***
3. Mechanical Energy (X_3)	6.72003155	2.6697	0.00***
4. Biological Energy (X_4)	-0.84842061	0.3511	0.03*
5. Chemical Energy N (X_5)	-2.50803420	1.2448	0.06
6. Chemical Energy P_2O_5 (X_6)	0.17059859	1.0526	0.58
7. Chemical Energy K_2O (X_7)	0.12608490	0.2651	0.63
8. Chemical Energy Herbicide(X_8)	0.05757435	0.6592	0.93
Return to Scale (RTS)	2.15963		
Durbin Watson Test (DW)	2.103729		
R-square	0.98		

*** Significance at 1% level

** Significance at 5% level

* Significance at 10% level

Appendix 1n: Econometric Estimation Results for Direct and Indirect Energy for Maize Production.

Endogenous variable:	**Maize yield**		
Exogenous variables	Coefficients (β_1)	Std. error	P-value
	$Model\ VI : \ln Y_i = \beta_1 lnDE + \beta_2 lnIDE + e_i$		
1. Direct Energy (DE)	0.008754004	0.0367	0.00***
2. Indirect Energy (IDE)	0.882852412	0.0348	0.00***
Return to Scale (RTS)	0.891606		
Durbin Watson Test (DW)	2.151997		
R-square	0.94		

*** Significance at 1% level

** Significance at 5% level

* Significance at 10% level

Appendix 1o: Estimated parameters of the yam production function

Endogenous variable:	**Yam yield**		
Exogenous variables	Coefficients	Std. error	P-value
$Model\ VII : \ln Y_i = \alpha_1 lnX_1 + \alpha_2 lnX_2 + \alpha_3 lnX_3 + \alpha_4 lnX_4 + \alpha_5 lnX_5 + \alpha_6 lnX_6 + \alpha_7 lnX_7 + \alpha_8 lnX_8 + e_i$			
1. Manual Energy (X_1)	-0.14937071	1.6405	0.00***
2. Thermal Energy (X_2)	0.08818699	0.2260	0.01***
3. Mechanical Energy (X_3)	0.15034975	0.1546	0.00***
4. Biological Energy (X_4)	0.16875439	0.5332	0.00***
5. Chemical Energy N (X_5)	0.03868375	0.3318	0.63
6. Chemical Energy P_2O_5 (X_6)	0.60388466	0.6079	0.00
7. Chemical Energy K_2O (X_7)	-0.11359745	0.3293	0.29
8. Chemical Energy Herbicide(X_8)	0.59838247	0.8678	0.01***
Return to Scale (RTS)	1.385274		
Durbin Watson Test (DW)	2.125837		
R-square	0.96		

*** Significance at 1% level

** Significance at 5% level

* Significance at 10% level

Appendix 1 p: Econometric estimation results for direct and indirect energies for yam production

Endogenous variable:	**Yam yield**		
Exogenous variables	Coefficients (β_1)	Std. error	P-value
	$ModelVIII : \ln Y_i = \beta_1 lnDE + \beta_2 lnIDE + e_i$		
1. Direct Energy *(DE)*	0.5413878	0.1988	0.00
2. Indirect Energy (IDE)	0.6009862	0.1292	0.00
Return to Scale (RTS)	1.142374		
Durbin Watson Test (DW)	1.884955		
R-square	0.92		

*** Significance at 1% level

** Significance at 5% level

* Significance at 10% level

Appendix 2:

Appendix 2a: One of the Rice Farm Surveyed

Appendix 2b: Some Tied-Up Bundles of Harvested Rice Crop on the Farm

Appendix 2c: Rice Being Threshed Manually by an Employed Male Labour

Appendix 2d: Rice Packed at the Store after Harvest

Appendix 2e: Some Threshed Rice

Appendix 2f: Rice Pre- cleaner in Igbemo Rice Mill

Appendix 2g: A Rice Parboiler

Appendix 2h: Rice Drying process by one ton per/batch dryer

Appendix 2i: A Rice Sorter

Appendix 2j: A Rice De-stoner

Appendix 2k: Rice Being Sorted Manually by the Female Labour.

Appendix 2l: Some Sealing Machines used in the Packaging of Rice

Appendix 2m: Maize sprouting out of the soil

Appendix 2n: A Planter in use at One of Large Scale Farms

Appendix 2o: Some Maize at One Month of Growing

Appendix 2p: Maize at About One and Half Month of Growth

Appendix 2q: Maize Stored in a Wooden Crib with Metal Roof in one of the large farms.

Appendix 2r: Maize being threshed by a male labour (Large farm)

Appendix 2s: Maize being threshed by a male labour (Medium farm)

Appendix 2t: Threshed Maize in 100 kg Bag.

Appendix 2u: Manual Labour Employed for Heap Making in One of the Large Farms

Appendix 2v: Yam Plant before Staking in One of the Surveyed Farms

Appendix 2w: Fertilizer Application Operation in One of the Medium Farm

Appendix 2x: Weeding Operation by Labourers in Medium Yam Farm

Appendix 2y: Yam Stored in One of the Large Farms

Appendix 2z: Yam Loaded in a Truck for Transportation to the Market

APPENDIX 3

QUESTIONNAIRE FOR THE FARM SURVEY ON MODELLING ENERGY INPUTS, OUTPUTS AND CONSUMPTION PATTERNS OF SELECTED CROPS IN NIGERIA

Section A:The Farm Information

1. The name of the farm ………………………………………………………………………
2. The address of the farm ………………………………………………………………………
3. The farm size ………..………………………………………………………………………
4. Level of mechanization

   …………………………………………………………………………
5. No of workers

   ……………………………………………………………………………………….

Section B: Information on Methods or Type of Farm Practices

1. Do you plant crop or not? yes / No
2. What varieties do you plant?
   - i. …………………………………………..
   - ii. ……………………………………………
   - iii. …………………………………………….
   - iv. …………………………………………….
3. How many acre or hectare do you plant crop on ……………………………………………….
4. Is the farm fully mechanized ………………………………………………………….
5. Sources of Planting materials (seed, fertilizer, Herbicide?………………………………………
6. Planting spacing? …………………………………………..

Section C: Machines and Labor Utilization for Crop Production.

Note: All answer should be per ha of land

Answer 1 if the operation was done by machine and 1a if the was done manually.

S/N	Field operation	Prime mover	Amount of fuel / materials used in litres,bag or gallon	Cost of fuel/ materials used in Naira	No of persons Required	Time of Required (Hr)	Cost of labour in Naira	Total Cost in Naira
1.	Bush clearing							
1.a	Bush clearing	manual						
2.	Primary tillage							
2.a	Manual							
3.	Secondary tillage							
3.a	Manual							
4.	Other operations : Ridging							
4.a	Manual							
8.	Planting							
9.	Fertilizer							
10.	Herbicide							
11.	Insecticide							
11.	Pre-emergence herbicide spraying							
12.	Post-emergence herbicide Spraying							
13.	Application of							

	Fertilizer							
14.	Application of insecticide							
15.	Inter-row weeding							
16.	Complete harvesting							
18.	Transportation to market							