

Energy consumption pattern in yam production: case study of Benue State, Nigeria

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Abstract: Energy consumption in agricultural production has significant economic and environmental implications. Despite Nigeria's position as the world's largest yam producer, there are few empirical study on the energy consumption patterns of yam production systems remains limited. This study assessed energy use pattern for yam production in Benue State, Nigeria, using data collected for two farming seasons from eighty-one (81) farms consisting of small, medium, and large farms. Standard energy equations were used to convert the quantity of resources used to their energy equivalent. The farms were evaluated using standard performance indicators. Human labour, thermal, machinery and chemical energy were the dominant energy sources across all farm categories. Energy analysis reveals that the average total energy inputs were 19835.08, 19392.17 and 19024.37 MJ ha⁻¹. The average energy outputs achieved were 75098.69, 76745.6, and 77961.6 MJ ha⁻¹, respectively. The energy ratios obtained were 3.78, 3.95 and 4.09, respectively, suggesting that energy was used efficiently. Large farm exhibits the highest level of efficiency compared to small and medium farms. The contributions of indirect energy were 18899.17, 18393.66, and 17957.03 MJ ha⁻¹ which represented 95.39%, 94.95%, and 94.48% of the total energy, respectively. These findings indicate that the production of yam in Nigeria depends heavily on the indirect energy form dominated by biological and chemical energy, while large-scale yam cultivation is less dependent on indirect and non-renewable energy sources. In addition, it highlighted inefficiencies in agrochemical, biological energy and labour utilization, emphasizing the need for mechanization. It also provides empirical evidence to guide sustainable yam production and energy policy formulation in Nigeria.

Keywords: yam, energy resources, sustainability, renewable energy, energy efficiency, crop production

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1 Introduction

Several species of plants that belong to the Dioscorea (Dioscoreaceae) family that form edible tubers are referred to as yam (CABI, 2017). Tubers are a starch-based crop commonly cultivated in the tropics and mainly produced in West Africa's savannah region. Different yam varieties are also cultivated in

Caribbean countries such as Brazil, Haiti, Colombia, Cuba and Jamaica (FAOSTAT, 2013). It is an annual rhizome that has more than 600 species, six out of them are economically and socially viable for food, money and medicine (IITA, 2009). Some common yam varieties include *Dioscorea alata* commonly refers to as water yam, *Dioscorea rotundata* also known as white yam, *Dioscorea cayanensis* called yellow yam,

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Dioscorea esculant known as Chinese yam and three-leaf yam (Sugihara et al., 2020).

Yam is Nigeria's fourth of ten major cultivated crop and remain a staple that is cultivated in different regions within the ecological zones and food hubs in Nation (Statista, 2019; Merem et al., 2024). Africa is the largest producer of yam globally accounting for over 94.63% of the world's total yam production hailing from west Africa mostly from Nigeria, Ghana, Benin, Cote D'Ivoire, and Togo. Nigeria accounts for over 66.9% and 68.4% percent of yam production globally and in African, respectively and remains the largest yam producer in the world with an annual production of 45.41 million metric tons in 2022. Yam is predominantly cultivated in Benue, Taraba, and Nasarawa states where they are mostly exported to other countries. Yield of yam in most West African exceed yield obtained in Nigeria. The average yield of yam obtained in Ghana and Benin were 18.22 tons ha⁻¹ and 13.76 tons ha⁻¹, respectively. Ethiopia has the highest yield of 29.2 tons ha⁻¹ of yam globally. The average annual yield of yam in Nigeria was 7.94 tons ha⁻¹ (FAOSTAT, 2022). This yield gap indicates inefficiencies in input use and techniques for yam production.

The role of yam as a staple in the diet of Nigerians cannot be overemphasized. Yam is a good source of energy as it contains carbohydrates with little fat and protein. Raw yams are only moderately nutrient dense, with significant amounts of potassium, manganese, copper, antioxidants, thiamin, fiber and vitamin C and B6 (Mudiope et al., 2012). Raw yams have the highest potassium content among the world's top 10 staple foods. Yams tend to have a lower glycemic index, approximately 54% glucose per 150 gram serving, compared to potato products (Ampofo, 2021). It provides over 258 dietary calories per day to over 150 million residents in West Africa and serve as sources of food for many households in Nigeria, thus yam is believed to key to food security (IITA, 2009). It is a major source of income for millions of farmers and foreign exchange for the government (Eyinla et al., 2022). Additionally, Nigeria serves as the best global

production site because consumer prefer a certain trait in the taste of the yam. Yam can be grilled, roasted, smoked, fried using oil, boiled and crushed in a mortar to form paste (pounded yam). It can be eaten with beans, butter, plantains, sweet potato, chicken, pumpkin leave sauce and palm nut soup (Umar et al., 2006). Yam is blanched and dried to make a brown powder popularly called Ebubo. The brown powder is mixed with a boiled water to form yam pudding known as Amala which is eaten with any form of soup including egusi, vegetable and other local soup. Yams also have the potential to become Nigeria's leading export if fully exploited (FAO, 2018).

The resources used by farmers to produce yams include seeds, labour, chemicals and fertilizers. Currently, yam production in Nigeria is characterised by many problems which include high cost of ridge preparation, weed pressure, decline in soil fertility and crop diseases. This mystery is exacerbated by inefficiencies in the yam business, which is experiencing a decline in exports. In addition, yam production in Nigeria also experiences high labour demand, low yield per hectare compared to other root crops, relatively large amount of plant material required, and long growing period (Bassey, 2017).

Maikasuwa and Ala (2013) examine factors affecting yam production in certain regions of Nigeria and they find that factors of production such as labour, finance, and inputs such as fertilizers have great influence on yam production productivity. Although Nigeria is the world's largest yam producer, the low productivity level of 29.2 tons per hectare is a concern compared to Ethiopia. The low productivity in the production of yam could be improved by improving the use of land, labour and production resources (Nwosu and Okoli, 2010). Effective use of farming resource will improve productivity, profitability and promote the economy of rural communities (Singh et al., 2002). In addition, to reduce production costs, efficient use of energy inputs, reduces environmental distortions caused by excessive use of natural resources. However, few published studies have investigated the efficiency of energy resources used in

yam production in Nigeria.

Modern agriculture relies heavily on various form of energy for its operations. it utilizes different energy sources, including diesel fuel, electricity, and human and animal labor, to perform tasks such as land clearing, tillage, planting, water pumping, chemical application, irrigation, and equipment maintenance (Imran et al., 2020). The heavy usage of energy for crop production contributes significantly to the environmental issue while increasing production costs and decreasing productivity. Evaluating energy utilization in agriculture operations is crucial for maximizing economic and environmental benefits and improving crop production efficiency (Sharifi Nia et al., 2024). In general, maximizing energy efficiency in agricultural operation is crucial for cutting energy consumption, reducing energy expenses, and lessening environmental harm emanating from an agricultural production (Nabavi-Pelesaraei and Damgaard, 2023). Maximizing energy efficiency and assessing environmental indicators in crop farming is necessary for sustainable agricultural practices. Maximizing energy efficiency involves finding ways to reduce the amount of energy used to perform a specific task or operate a system (Simpeh et al., 2022).

An energy analysis would provide better energy resources management approaches to get the highest yields while using less energy to produce crops. It will in addition, assist policymakers in making sound policies for energy usage. The energy indices that can be used to measure or compare the success of agricultural production systems include net energy gain, energy use efficiency, energy productivity, and profitability (Imran et al., 2020).

Energy analysis had been applied to several crop productions to establish the energy consumption pattern and identify areas of high energy usage, including cassava (Bamgboye and Kosemani, 2015), rice (Kosemani and Bamgboye, 2020), maize (Kosemani and Bamgboye, 2021), soybean (Jekayinfa et al., 2022), and peanut (Abbas et al., 2024). Furthermore, some studies attempted not only to reduce energy consumption in agroecosystems, but

also to optimize the agricultural production system. Among the most extensively utilized procedures for optimizing and evaluating energy utilization in agricultural production systems are data envelopment analysis (DEA) and artificial neural network (ANN) imperialist competitive algorithm (ICA). Furthermore, strategies utilized for minimizing greenhouse gas emissions from crop cultivation include life cycle assessment (LCA), LC-IMPACT assessment method (Rashidi et al., 2024).

Nigeria's agricultural sector is struggling to meet rising food demand, with production growing at only 1.5% per year compared to demand growth of over 3.2%. This has resulted in food deficits, rising prices, and increased import bills (Olubunmi-Ajayi et al., 2023). This situation generated concern among government officials, researchers, legislators, and farmers, emphasizing the importance of greater agricultural productivity through optimal resource allocation. Efficient use of energy resources is crucial for yam farmers to achieve their economic goals within the limited resources. However, lack of rural labour and increased energy resources prices have led to yam becoming a luxury meal (Olutumise, 2020).

Despite Nigeria being the largest producer of yam, comprehensive empirical investigations into the energy consumption pattern of yam production systems remain limited. In particular, there is insufficient quantitative evidence regarding the measurement of direct and indirect energy inputs, the assessment of input–output energy relationships, and the evaluation of energy-use efficiency indices. Furthermore, comparative analyses of energy consumption patterns across small, medium, and large-scale yam production systems are scarce. This knowledge gap constrains evidence-based policymaking and limits the formulation of targeted interventions aimed at improving energy efficiency, reducing production costs, and minimizing environmental impacts in yam production systems, particularly in Benue State, Nigeria's leading yam-producing region. This study was conducted to determine energy consumption pattern and analyze the

input–output energy efficiencies for small, medium and large yam production in Benue State, Nigeria. Furthermore, it seeks to analyse the effect of indirect and direct energy consumption on yield, as well as to compute energy productivity and yam production system's agrochemical energy ratio. The energy consumption pattern for yam production must be assessed in order to better understand the current situation and enhance resource utilization. Furthermore, it will help in reducing the quantity of input use in yam production system without compromising output. The effective use of energy in yam production would boost production, productivity, and profitability while also making yam production sustainable.

2 Materials and methods

2.1 Study region

This experiment was conducted across three local government area of Benue State: Ukum, Kwande, and Katsina-Ala. Benue State was chosen because yam is primarily grown in the state, where over four million metric tones of yam are produced each year, sold locally, and exported to other nations. Three (3) Local Government Areas (LGAs) were purposively selected among the state's 23 LGAs because they are among the four local government known for yam production that is devoid of insecurity activity. The three local governments chosen are well-known for yam production in the region and provide genuine representations of yam production across the country. The region is a tropical climate with annual average rainfall ranging from 158mm to 180mm and average temperature which varies between 24.16°C and 33.04°C.

2.2 Data collection

This study investigated eight- one (81) yam producers from three (3) farming communities in each of the three local government areas for two growing seasons. Nine (9) yam farms, consisting of small, medium, and large farms, were randomly selected from each of these communities. Small farms are those whose farm size is less than 2 ha, medium farms are

those whose farm size is between 2 and 10 ha, and large farms are those whose farm size is more than 10 ha. Different forms of resources used for yam production were surveyed, converted to energy equivalent in order to establish the energy consumption patterns. Production inputs for 2020 and 2021 growing seasons in each stage of production were determined for land preparation, planting, weeding, mulching, stacking, fertilizer application and transportation to storage facilities or market). Energy related data including machinery, fuel, labour, seed, fertilizer and herbicide were measured via structured questionnaires and direct measurement using standard instruments. The quantity of the fuel and chemical herbicide used was measured using a measuring cylinder and seed and fertilizer were weighed using a weighing balance (Scout pro, OHAUS).

2.3 Measured parameters and energy conversion procedures

Parameters need to measure the energy demand including quantity of fuel, quantity of fertilizer, time spent on an operation, weight of yam determined for each at each stage of operation are as shown in Table 1. The energy equivalent of the data was obtained using standard equation as shown in Table 2. Standard equation used for the energy input estimation were obtained from literatures (Kosemani and Bamgboye, 2020).

2.3.1 Manual energy

Manual energy used in the production of yam was evaluated by multiplying the number of labourer involved in the activity by 0.27 and 0.23 which are energy equivalent of male labour and female labourer respectively (Bamgboye and Jekayinfa, 2006). Manual energy input was evaluated by employing Equation (1).

$$Em^m = 3.6 (0.075 \times N \times t_o) \quad (1a)$$

$$Em^f = 3.6 (0.065 \times N \times t_o) \quad (1b)$$

Where,

t_o is actual time spent on the operation;

N is number of human workforce;

0.075 and 0.065 kW are the average output power that average male and female workers can supply at a continuous energy consumption of 0.30 kW,

respectively.

$$Ed^t = 47.8 \times d_t \quad (2)$$

2.3.2 Thermal energy

Energy input from diesel fuel was estimated by lower heating value of diesel fuel by the quantity of diesel used for an operation. Energy from fuel (thermal energy) used was evaluated by applying Equation (2).

Where,

47.8 is the calorific value of diesel (lower heating) MJ L⁻¹;

d_t is the quantity of diesel fuel (l).

Table 1 Parameters measured for estimating consumption in the production yam

S/N	Agronomic activity	Energy type and equipment	Energy parameter
i.	Land preparation	Manual: cutlass	Quantity of fuel consumed, l Time (t) spent, hr No. of labour involved
ii.	Planting	Manual	Time (t) spent, hr No. of labour involved. Weight of yam set used, kg
iii.	Weeding	Manual: Hoe Knapsack sprayer	Time (t) spent, hr Herbicide in litre used, l No of labour involved
iv	Mulching	Manual	Time spent, hr No. of labour involved
v.	Staking	Manual	Time spent, hr No of labour involved.
vi.	Fertilizer Application	Manual	Time spent, hr No of labour involved. Amount of fertilizer used, kg
vii.	Harvesting	Manual	Time spent, hr Number of person involved
viii.	Transportation	Mechanical: Truck Manual	Quantity of fuel used, l Time spent, hr Number of person involved

Table 2 Energy equivalent of inputs and output used

	Energy inputs	Energy equivalents (MJ)	Reference
1	Human labour	0.27	Bamgboye and Jekayinfa (2006)
2	Diesel fuel (l)	47.8	Bamgboye and Jekayinfa (2006)
3	Fertilizer (kg)		
	Nitrogen fertilizer	78.1	Kosemani and Bamgboye (2020)
	2. Phosphorous	17.4	Kosemani and Bamgboye (2020)
	3. Potassium	13.7	Kosemani and Bamgboye (2020)
4	Chemical (kg)	120	Singh et al. (2002)
5	Yam sett	6.4	Olatoye et al. (2013)
	Energy output		
	Yam	6.4	

2.3.3 Chemical energy

chemical energy from fertilizer was determined by employing Equation (3a) while chemical energy from herbicide was determined using Equation (3b).

$$f_e = \left(\sum_{n=1}^n \frac{N.N_{eqv}}{AP} + \frac{P_2.O_5.P_{eqv}}{AP} + \frac{K_2O.K_{eqv}}{AP} \right) \text{ MJ} \quad (3a)$$

$$h_e = 3.6(0.075 \times N \times t_o) + (H_{her} \times H_{eqv}) \text{ MJ} \quad (3b)$$

Where,

K_{eqv} is 13.7MJ kg⁻¹;

N_{eqv} equals 78.1 MJ kg⁻¹;

P_{eqv} equals 17.4MJ kg⁻¹;

AP is the planted area (ha);

n is the compound fertilizer for applied time n th;

H_{eqv} of 120 and 10 MJ kg⁻¹ was used when granular and liquid herbicide, respectively (Singh and Mittal, 1992);

H_{her} is the quantity of herbicide used (kg);

H_{eqv} is denotes the energy equivalent value of herbicide (238 MJ/ kg) .

2.3.4 Mechanical energy

The mechanical energy input was determined using tractors production energy and agricultural

machines per unit area using the Equations (4) and (5) (Demircan et al., 2006).

$$E_m = \frac{W_t \times E}{T \times C_a} \text{ MJ} \quad (4)$$

Where,

W_t is weight of tractor used (kg);

E is constant for tractor, (158.3 MJkg⁻¹);

T is economic life (h) of Tractor used;

C_a is field capacity(effective) (ha h⁻¹);

$$C_a = \frac{(S \times W \times E_{fi})}{10} \quad (5)$$

Where,

W is implement width (m);

S is Tractor speed;

E_{fi} is Field efficiency;

2.3.4 Biological energy

Biological energy from the yam sett was determined using Equation (6).

$$p_e = Q_{sett} \times Q_{eqv.sett} \text{ MJ} \quad (6)$$

Where,

Q_{sett} is the quantity of yam planted in kg;

$Q_{eqv.sett}$ is the energy equivalenet of yam.

2.4 Form of energy used in yam production

Energy use in the study region for yam production was classified into direct and indirect forms. Direct energy (DE) includes manual, thermal (diesel fuel); while indirect energy (IDE) is mechanical, chemicals (fertilizer and herbicide) and seeds.

The procedure used for determining energy consumed in stage of production and the equation used are as follows:

2.5 Land preparation

The farms were cleared and tilled in all the categories of yam farms manually. The time spent to clear the bush and tilling the farms and No. of labour and their gender were recorded. The energy used for bush clearing and tillage were determined using equation 1a.

2.6 Planting

Yam setts were manually planted in all the categories of yam farms. The weight of yam sett (kg) planted, the useful time on the operation and number of labourer that plant were the parameters used for

calculating the energy input. The energy input during yam planting include manual and biological energy were determined using Equation (7).

$$p_e = (Q_{sett} \times Q_{eqv.sett}) + 3.6(0.075 \times N \times t_o) \text{ MJ} \quad (7)$$

2.7 Mulching

Mulching of heaps using biomaterial such as grass or leaves in all the categories of yam farm done manually. The time involved in the activities and the number of labour were determined from the survey and the value was computed using Equation 1a.

2.8 Staking

Good stakes from cassia, or bamboo was used to support the yam vine. The stake between 2 to 2.5m high was cut manually. The time required and the no. of labourer did the staking was recorded during the operation. Energy consumed during the operation was calculated using Equation 1a:

2.9 Weeding

Weeding was carried out manually using hoe and chemically. Pre- and post-emergence application of herbicides using knapsack sprayer generally was done manually. The time spent on weeding operation, no. of labourer herbicide in litres used were obtained. Equation 1a was used to determine energy consumed for weeding manually using cutlass and hoe, while Equation 3b was used when it was done via chemical herbicide.

2.10 Fertilizer application

N.P.K fertilizer was applied manually generally in all the yam farm surveyed. Energy consumed in the operation was calculated from parameters including the quantity of NPK fertilizer (kg) used and no. of labourer using 78.1, 17.4 and 13.7 MJ kg⁻¹ as the energy equivalent value for N, P₂O₅ and K₂O, respectively, using Equation 3a and 1a (Demircan et al., 2006).

2.11 Harvesting

Energy required to harvest yam from the heaps was calculated using parameter including the useful time on harvesting and No. of labour who harvested the yams. Energy input in the operation was determined using Equation (1a).

2.12 Transportation to market or storage facilities

Energy input in conveying the harvested yam from the field to the market or store was calculated from the operation time and the No. of workers and quantity of diesel fuel used. The quantity of diesel was determined by refuelling the tractor's fuel tank to the brim, then measure volume of diesel needed to refill the tractor's fuel tank after the operation. The energy consumed for transporting yam to the market or storage facilities was determined using Equations (2) and 1(b).

$$tr_e = 47.8 D + 3.6(0.075 nt_o) \text{ MJ} \quad (8)$$

2.13 Energy indicator of energy use in yam production

Following the procedure of Bamgboye and Kosemani (2015), energy indicators used for measuring the performance of each category of farms are energy ratio (e_r), energy productivity (e_p), net energy (e_n) and agro-chemical energy ratio (e_{agr}). The equations representing the indicators are presented in Equations (9)-(13).

$$e_r = \frac{E_o \text{ (MJ ha}^{-1}\text{)}}{E_i \text{ (MJ ha}^{-1}\text{)}} \quad (9)$$

Where,

E_o is energy output;

E_i is energy input.

$$e_p = \frac{C_o \text{ (kg ha}^{-1}\text{)}}{E_i \text{ (MJ ha}^{-1}\text{)}} \quad (10)$$

Where,

C_o is yield output.

$$e_n = E_o \text{ ((MJ ha}^{-1}\text{))} - E_i \text{ ((MJ ha}^{-1}\text{))} \quad (11)$$

$$e_{agr} \text{ (\%)} = \frac{E_{ic} \text{ (MJ ha}^{-1}\text{)}}{E_i \text{ (MJ ha}^{-1}\text{)}} \quad (12)$$

Where,

E_{ic} is energy input from chemical energy;

E_i is total energy input;

$$E_o = y_o \times \alpha \quad (13)$$

Where,

y_o is the quantity of yam (kg ha⁻¹);

α is energy equivalent factor of yam MJ kg⁻¹.

2.14 Statistical analysis

Data obtained from each of the 81 yam producers were considered as separate experimental units, with the two seasons acting as temporal replications to

improve reliability and account for seasonal variability.

Energy inputs and outputs were summarized using descriptive statistics, such as mean, standard deviation, and percentage contribution. Energy performance indicators were calculated using standard energy balance formulae. Significant variations in energy inputs and energy efficiency indices among the three farm groups were found using one-way analysis of variance (ANOVA) at a 5% level of significance ($p < 0.05$). When significant differences were discovered, Duncan's Multiple Range Test (DMRT) was used to separate the means post-hoc.

3 Results and discussion

3.1 Energy input in yam cultivation

Table 3 displays the results for the distribution of the total energy input for yam cultivation by different levels of farms. The range for the total energy input was from 19,778.77 to 19,941.62 MJ ha⁻¹ for small-scale farms, from 19,282.51 to 19,565.31 MJ ha⁻¹ for medium-scale farms, and from 18,989.22 to 19,086.46 MJ ha⁻¹ for large-scale farms. The result from the ANOVA test showed that the total energy input varied significantly for different levels of farms ($p < 0.05$). The result from the post-hoc test by the DMRT showed that the total energy input was significantly higher for small-scale farms compared to medium and large-scale farms. Similarly, the result from the post-hoc test by the DMRT showed that the total energy input was significantly higher for medium-scale farms compared to large-scale farms at the 5% level of significance. The variation in the level of herbicide application and the weight of yam setts for planting was responsible for the variation in the total energy input for different levels of farms. The average values for the total energy input for small-scale, medium-scale, and large-scale farms were 19,835.08, 19,392.17, and 19,024.37 MJ ha⁻¹, respectively.

The biological energy, mainly from yam setts, accounted for the highest percentage in the overall energy input for all farm categories. This may be attributed to the inherent characteristics associated with yam cultivation, which requires comparatively

larger planting materials compared to other root crops. The progressive decline in energy input from small- to large-scale farming may be attributed to better management and possible economies of scale in managing larger inputs.

The energy inputs in this study are higher compared to the range of 7,388.6 to 10,888.66 MJ ha⁻¹ for cassava production in Nigeria as reported by Bamgboye and Kosemani (2015). This could be attributed to the higher energy equivalent value associated with yam setts compared to cassava stem cuttings, which may require substantially lower biological energy input. The results are in line with the theoretical postulations that crops requiring larger planting materials and higher input levels are associated with higher energy values.

In this study, the values of the energy input are relatively lower compared to those recorded for peanut production (42,748.10 MJ ha⁻¹; Nia et al., 2024), glasshouse tomato (81.36 GJ ha⁻¹; Ozkan et al., 2011), and pear production (172.61 GJ ha⁻¹; Tabatabaie et al., 2013). The higher values recorded for these crops can be attributed to the intensive use of fertilizers, irrigation systems, greenhouse structures, and mechanization. On the contrary, yam production in Benue State is mainly rain-fed and semi-mechanized, which limits the energy input values. The values recorded for yam production in this study are relatively higher than those recorded for rice (14,067–14,813 MJ ha⁻¹; Kosemani and Bamgboye, 2020), wheat (11,984 MJ ha⁻¹; Taghavifar and Mardani, 2015), and soybean (12,127.86 MJ ha⁻¹; Jekayinfa et al., 2022). This study suggests that yam production is relatively more energy-intensive compared to the aforementioned crops, mainly due to the inherent energy content and the need for manual labor.

Another notable structural characteristic of yam production in this study was the dominance of indirect energy, particularly the use of biological and chemical energy. The indirect energy values accounted for more than 96% of the total energy input for different types of farms. The dominance of indirect energy indicates that the yam production in the region mainly relied on

non-renewable and embodied energy forms such as fertilizers and agrochemicals. This may be a major environmental concern and a threat to sustainable agriculture due to the greenhouse effect that may result from the use of fertilizers (Nabavi-Pelesaraei and Damgaard, 2023). The relatively high level of biological energy indicates that there may be some inefficiencies in the management of planting materials. The use of larger yam setts increases the level of energy input without a corresponding increase in yield if the setts are not optimally sized. Research into root and tuber crops has shown that the optimization of sett sizes can result in a significant reduction in the level of biological energy input without compromising the level of yield performance. The reduction in the weight of the sett by the use of seed yam technologies, such as miniset technology, can result in a significant reduction in the level of energy input and improve the level of energy efficiency.

The reduction in the level of energy input from small-scale to large-scale farms indicates that increasing the level of farm size may improve the level of energy efficiency. Large-scale farms recorded a relatively low level of biological and chemical energy intensity per hectare, which may be a result of good agronomic management and the ability to allocate the input levels optimally. This is similar to the findings from other crops, which show that the level of farm size has a positive effect on the level of energy efficiency in the use of energy.

3.2 Energy use pattern in yam cultivation

The various forms of energy resources utilized in all categories of small, medium, and large-scale yam farms included manual, mechanical, thermal, biological, and chemical energy, as shown in Table 3. The similarity in the application of all forms of energy in all categories of farms is an indication of similar farming practices and low mechanization in all farms in the study area. Primary farm operations such as tilling, planting, staking, and harvesting of yams in all farms were manual, while mechanical operations such as transportation and application of agrochemicals in farms were limited.

The biological and chemical energies dominated the energy input in all categories of farms, with 9,719.00, 9,382.33, and 9,157.00 MJ ha⁻¹ of biological energy (yam sett) utilized in small, medium, and large-scale farms, respectively, contributing 48.99%, 48.38%, and 48.00% of total energy input in the farms, respectively. From the ANOVA test, differences in biological energy input in various categories of farms were significant ($p < 0.05$). Duncan's multiple range test further showed that small-scale farms utilized significantly higher biological energy compared to large-scale farms, with medium-scale farms in between. These differences in biological energy in various categories of farms are attributed to differences in sett weights (95-185 g) and density of planting materials in various farms, which is in agreement with the findings of Shehu et al. (2010), which showed that seed yam, fertilizer, and labour are the most important factors affecting output and energy consumption in yam farms. This is consistent with other root and tuber crops, where seed energy is dominant, though in smaller quantities due to smaller seed size, such as stem cuttings in cassava farms.

Chemical energy, the second-highest contributor to total energy, accounted for 9,180.17, 9,011.33, and 8,825.03 MJ ha⁻¹ for the respective farm types (46.28%, 46.35%, and 46.46% of total energy). The major share of chemical energy is due to the use of fertilizers and herbicides. The relatively higher share of chemical energy may be attributed to the higher dependence on external agrochemicals. Though there was no significant difference found in the chemical energy of small and medium farms, there was slightly lower chemical energy in large farms, probably due to the more efficient use of agrochemicals and machinery.

The dominance of biological and chemical energy sources is quite contrary to the findings in the production of mechanized cereal crops, where fuel and machinery energy play more important roles. Kosemani and Bamgboye (2020) found total energy input to be in the range of 14,067 to 14,813 MJ ha⁻¹ in rice production, with more importance given to mechanical and fuel energy due to more mechanization

in rice production. Similar findings are reported by Taghavifar and Mardani, (2015) where total energy input was found to be 11,984 MJ ha⁻¹ in wheat production, with more importance given to fuel energy. However, perennial crops like glasshouse tomato production, reported by Ozkan et al. (2011) at 81.36 GJ ha⁻¹, and pear orchard production, reported by Tabatabaie and Mardani (2015) at 172.61 GJ ha⁻¹, have shown much higher total energy intensities due to the controlled environment and irrigation systems.

Mechanical energy inputs, which ranged from 388.70 to 449.44 MJ ha⁻¹, accounted for a mere 1.95%-2.62% of the total energy consumed in the region. Thermal energy inputs, which refer to the use of fuel, ranged from 244.75 to 332.20 MJ ha⁻¹, accounting for 1.23%-1.74% of the total energy consumed in the region. These findings corroborate the low level of mechanization in yam cultivation in the region. However, both mechanical and thermal energy inputs showed an increase with farm size, a clear indication of a gradual substitution of labour with mechanical energy in larger farms. This is in line with the theory of structural transformation in agricultural mechanization, which states that there is a greater substitution of capital for labour in larger farms.

On the other hand, manual energy, which was responsible for the smallest proportion of the total energy inputs, accounted for a mere 1.50%-1.52% of the total energy inputs, yet it was responsible for all field operations in yam cultivation. This is in agreement with Strapatsa et al. (2006) and Kosemani and Bamgboye (2020), who noted that manual energy, in its energy-equivalent form, is usually a small proportion of the total energy consumed in agriculture. There was a decline in manual energy with an increase in farm size, a clear indication of a gradual level of mechanization in larger farms.

Indirect energy consumption formed the larger percentage in total energy consumption, with values of 18899.17, 18393.66, and 17,957.03 MJ ha⁻¹, representing an approximate range of 94.48% to 95.39%. This could be attributed to the fact that the farming system highly depends on inputs such as yam

setts and fertilizers. On the contrary, the percentage formed by direct energy inputs was relatively small, ranging from 4.61% to 5.52%. The results show that the percentage formed by indirect energy consumption was higher compared to direct energy. This implies that efforts to improve efficiency in input materials such as seed and fertilizers are more important compared to efforts to improve fuel efficiency.

The percentage formed by renewable energy was in the range of 49% to 51%, mainly due to biological inputs. On the contrary, non-renewable energy inputs, which included fertilizers, agrochemicals, and diesel, formed an approximate range of 49% to 51%. The closeness in the range formed by these two energy sources shows that the farming system in the region moderately depends on non-renewable energy.

Table 3 Energy resources used for yam production in Benue State, Nigeria.

Unit operation	Energy input (MJ ha ⁻¹)		
	Farm categories		
	Small	Medium	Large
Manual energy	302.41 ^a	293.26 ^b	285.65 ^c
Mechanical energy	388.7 ^a	386.42 ^a	449.44 ^b
Thermal energy	244.75 ^a	318.8 ^b	332.2 ^b
Biological energy	9719 ^a	9382.33 ^b	9132 ^c
Chemical energy	9180.17 ^a	9011.33 ^a	8825.03 ^b
Energy input (MJ ha ⁻¹)	19835.08 ^a	19392.17 ^b	19024.37 ^c
Direct energy MJ ha ⁻¹)	912.70 ^b	977.94 ^a	1047.78 ^a
Indirect energy (MJ ha ⁻¹)	18899.17 ^b	18393.66 ^a	17957.03 ^c

Note: Means that has the desame letter in row are not significantly different at P <0.05..

Table 4 Operation-wise average energy consumed and output for yam in Benue State, Nigeria.

Unit operation	Energy input (MJ ha ⁻¹)		
	Farm categories		
	Small	Medium	Large
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 ₂ O ₅	1044.00	1044.00	1009.20
K ₂ O	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
Mechanical energy	38.02	94.82	137.61
Energy input (MJ ha ⁻¹)	19835.08 ^a	19392.17 ^b	19024.37 ^c
Yield (kg ha ⁻¹)	11734.17 ^{ab}	11991.50 ^a	12181.50 ^b
Energy output (MJ ha ⁻¹)	75098.69 ^{bc}	76745.6 ^b	77961.6 ^a

Note: In any row, means followed by a common letter are not significantly different at 5% level.

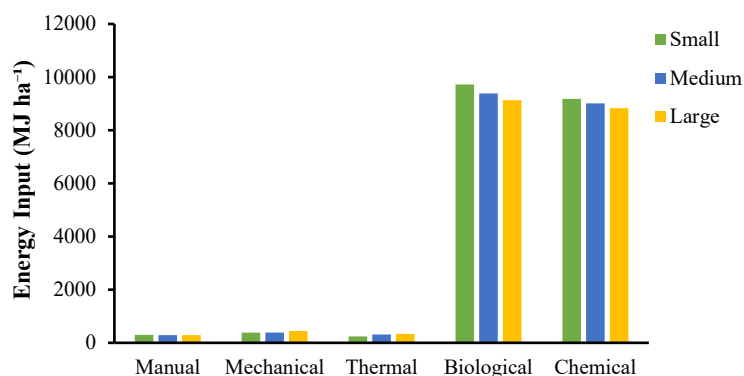
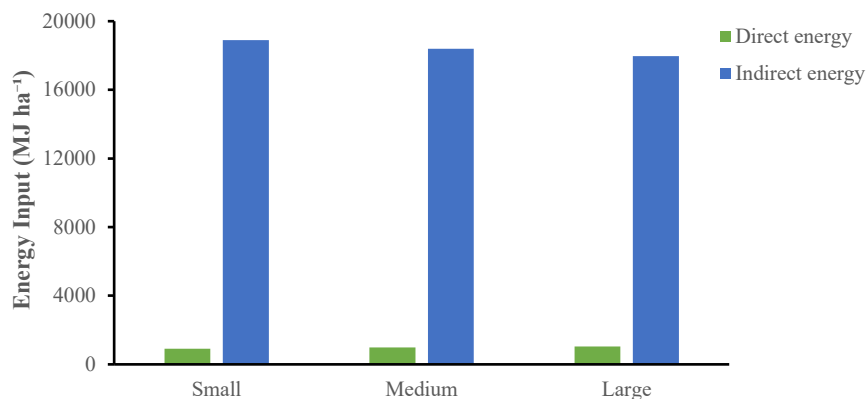


Figure 1 Energy consumption pattern for yam production

Figure 2 Pattern of energy forms used in yam production (MJ ha⁻¹)

Operation-wise energy use across the different farm categories is presented in Figures 3–5. In all farm sizes, planting (yam sett placement) and fertilization accounted for the largest proportions of total energy input. Energy consumed during planting was 9,739.88, 9,402.10, and 9,151.00 MJ ha⁻¹ in small, medium, and large farms, respectively, representing 49.10%, 48.48%, and 48.10% of total energy input. Similarly, fertilization required 8,870.67, 8,712.96, and 8,531.57 MJ ha⁻¹, contributing approximately 44.77%, 44.93%, and 44.84% of total energy use. The dominance of these two operations reflects the high quantity and energy equivalent of yam setts and mineral fertilizers applied during crop establishment and growth.

Significant differences were observed in energy consumption for planting and fertilization among farm categories. The amount of yam sett and fertilizer applied decreased with increasing farm size, suggesting more efficient input management in larger farms. In contrast, small and medium-scale farmers tended to use larger sett sizes under the assumption that bigger propagules enhance yield. However, this practice substantially increases biological energy input

without proportionate yield gains, thereby reducing overall energy-use efficiency.

Weeding operations consumed 699.68, 628.86, and 644.07 MJ ha⁻¹ across small, medium, and large farms, respectively. Tillage required comparatively little energy (64.98, 64.30, and 62.70 MJ ha⁻¹). Variations in weeding and tillage energy were largely attributable to differences in labour composition (age, gender, and work intensity) rather than mechanization level, as these operations were predominantly manual.

Energy used for transportation of harvested tubers increased progressively from small (309.93 MJ ha⁻¹) to medium (434.17 MJ ha⁻¹) and large farms (489.32 MJ ha⁻¹). This trend likely reflects greater average transport distances and larger volumes handled in bigger farms.

Harvesting consumed 56.52, 54.85, and 52.15 MJ ha⁻¹, representing approximately 0.27%–0.28% of total energy input. The relatively low contribution is attributable to the dominance of manual labour, which carries a low energy-equivalent coefficient. Mulching required the least energy input across all categories (5.47, 5.31, and 5.27 MJ ha⁻¹), accounting for less than

0.1% of total energy use.

Overall, the operational analysis confirms that energy consumption in yam production is heavily concentrated in input-intensive stages planting and fertilization rather than in mechanical field operations. This differs from highly mechanized cereal cultivation where tillage and harvesting often dominate energy expenditure.

3.3 Energy output in yam cultivation

The operational energy consumption of different categories of farms is represented in Figures 3, 4, and 5. Overall, planting/yam sett placement and fertilizer application were found to be the largest contributors to energy consumption in all categories of farms. Energy consumption during planting were 9,739.88, 9,402.10, and 9,151.00 MJ ha⁻¹ for small, medium, and large-scale farms, respectively, contributing 49.10%, 48.48%, and 48.10% to total energy input. Similarly, fertilizers required 8,870.67, 8,712.96, and 8,531.57 MJ ha⁻¹, contributing 44.77%, 44.93%, and 44.84% to total energy consumption. This was due to the large amount of yam setts and mineral fertilizers used during planting. Significant variation was noted in terms of energy consumption during planting and fertilizers in all categories of farms. This was due to a decline in the use of yam setts and fertilizers in large-scale farming compared to small- and medium-scale farming. This was due to efficient use of resources in large-scale farming. However, small- and medium-scale farmers used larger sett sizes based on the assumption that larger setts would result in increased yield. However, this increased biological energy input significantly without any corresponding increase in yield, resulting in decreased efficiency of energy use.

Weeding operation required 699.68, 628.86, and 644.07 MJ ha⁻¹ on small, medium, and large farms, respectively. Tillage activities required relatively lower amounts of energy, at 64.98, 64.30, and 62.70 MJ ha⁻¹. The variability in energy required for weeding and tillage activities may be attributed to the composition of labour in terms of age and gender rather than the level of mechanization, as these operations are largely done manually.

The energy input for transporting the harvested tubers increased from small to large farms. The energy input for small, medium, and large farms was 309.93, 434.17, and 489.32 MJ ha⁻¹, respectively. The energy input for harvesting activities was 56.52, 54.85, and 52.15 MJ ha⁻¹. This activity accounted for merely 0.27 to 0.28 percent of the total energy input. This may be attributed to the fact that the activity involves largely manual labor, which requires a lower coefficient of energy equivalent. The mulching activity required the least energy input for all farm sizes at 5.47, 5.31, and 5.27 MJ ha⁻¹. This activity accounted for less than 0.1 percent of the total energy input. The results from the operational analysis show that the energy input for yam farming is largely for planting and fertilizing activities rather than for mechanical activities in the field. This contrasts with cereal farming, which requires highly mechanized farming practices and for which tillage and harvesting are the major activities in energy input.

Mean yam tuber yields were 11,734.17, 11,991.50, and 12,181.50 kg ha⁻¹ for small, medium, and large farms, respectively as shown in Figures 3–5. These yields fall within the national average range reported by FAOSTAT (2021), which indicates average annual yam yields in Nigeria between 8 and 12 t ha⁻¹. However, yields in the study area remain lower than those reported for other West African countries, such as Ghana (18.22 t ha⁻¹) and Benin (13.76 t ha⁻¹). The relatively modest yield levels observed corroborate the findings of Fasusi et al. (2022) who characterized yam production in Nigeria as having comparatively low productivity and high production costs. Several factors contribute to this yield gap, including suboptimal seed quality, declining soil fertility, inefficient nutrient use, weed pressure, pests and diseases, and climate variability (particularly drought stress).

Energy outputs, calculated by converting yield to energy equivalents, were 75098.69, 76745.6, and 77961.6 MJ ha⁻¹ for small, medium, and large farms, respectively. Although energy output increased slightly with farm size, the increment was modest

relative to total energy input. This suggests that improvements in energy-use efficiency are more likely to result from optimizing input use rather than merely increasing scale. Compared with more intensive cropping systems reported in the literature such as greenhouse tomato production (Ozkan et al., 2011) or

orchard systems (Tabatabaie et al., 2013), yam production demonstrates moderate energy output but relatively high biological input intensity. This imbalance indicates that substantial efficiency gains could be achieved through improved seed technology and nutrient management.

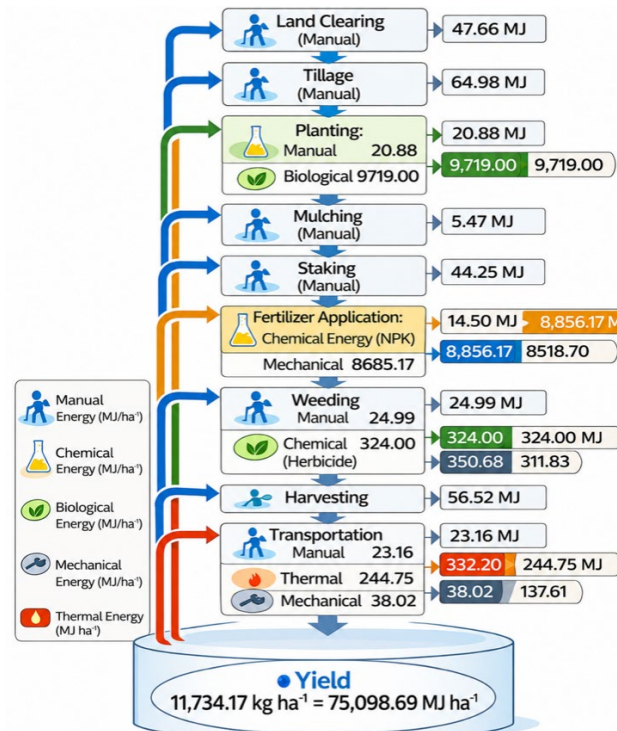


Figure 3 Small yam farm energy flow

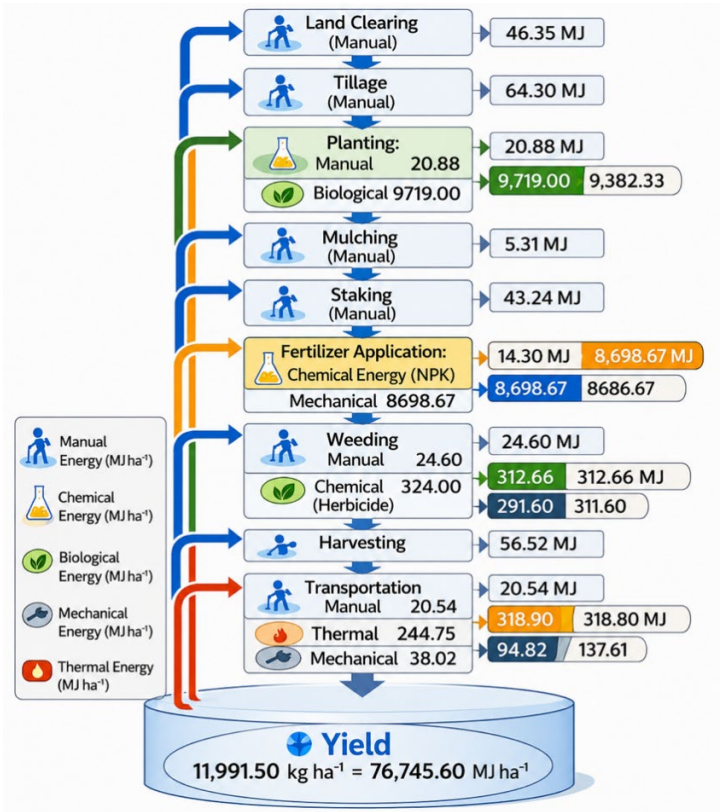


Figure 4 Medium yam farm energy flow

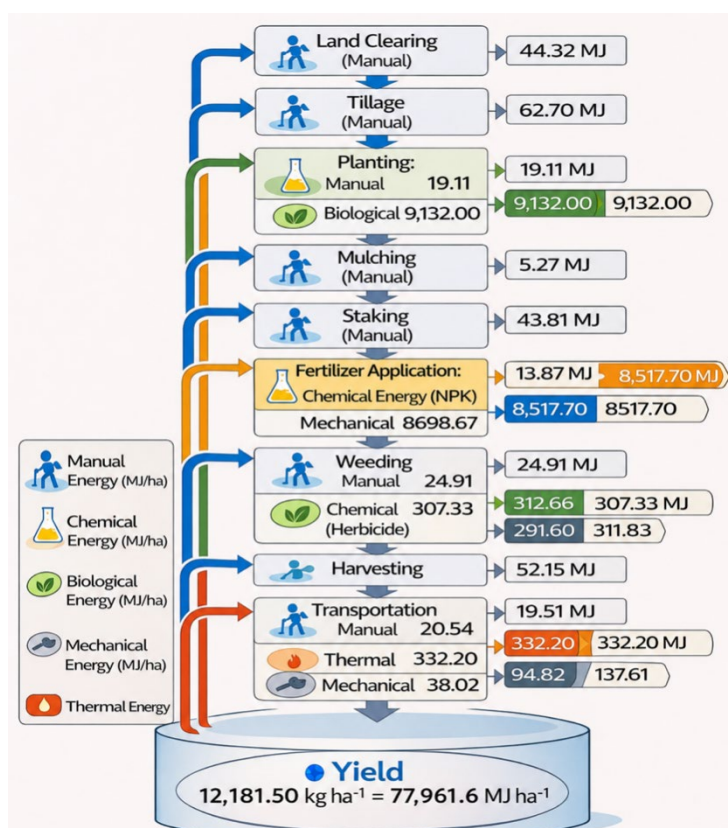


Figure 5 Large yam farm energy flow

3.4 Energy indicators in yam cultivation

3.4.1 The net energy values

As depicted in Figure 6(a), the net energy for yam production in the study area was found to be 55263.61, 57353.43, and 58937.23 MJ ha⁻¹ for small, medium, and large farms, respectively. According to the results of the one-way ANOVA analysis, significant differences in net energy were found among the farm categories. In addition, the results of the DMRT analysis revealed that large farms were found to have significantly higher net energy compared to small farms, while medium farms were found to have higher net energy than small farms. However, the positive net energy values obtained in this study for yam production in the study area show the energetic viability of yam production in the area, as the energy output was found to be higher than the energy input. In addition, the increasing trend in net energy with increasing farm sizes shows improved energy resource management in medium- to large-scale farms, which may be attributed to improved allocation of energy inputs, reduced biological energy intensity per unit of product, and improved operational efficiency in large farms.

The net energy values obtained in this study, the net energy values were found to be higher than the net energy of 46,655.77 MJ ha⁻¹ obtained by Bamgbaye and Kosemani (2015) in their study on the net energy of cassava production in Nigeria. In this case, the lower net energy value in the study by Bamgbaye and Kosemani, (2015) may be attributed to the substantially low yield of cassava obtained in their study. The average cassava yield obtained in their study was 9960.00.

3.4.2 Energy productivity

The energy productivity values as shown in Figure 6(b) were 0.59, 0.61, and 0.64 kg MJ⁻¹ for small, medium, and large farms, respectively. This implies that for every 1 MJ of energy invested in yam production, 0.59-0.64 kg of yam tuber was produced. It was evident from the ANOVA test that there was a significant difference in energy productivity among various farm categories ($p < 0.05$). DMRT test results showed that large farms had significantly higher energy productivity compared to small farms. Although there was a significant increase in energy productivity with an increase in farm size, it was still lower compared to 1.18 kg MJ⁻¹, which was recorded

in cassava production by Bamgboye and Kosemani (2015). This is attributed to a higher energy input intensity in yam production, especially in biological and chemical inputs.

Lower energy productivity implies a higher energy intensity in production, which might be a pointer to higher production costs, lower profitability, and a high risk of fluctuations in energy prices, in addition to land expansion to meet market demands. A direct proportionality between farm size and energy productivity implies that better management and mechanization of farms improve energy productivity in yam production. This is in line with what was established in Nigerian rice production by Kosemani and Bamgboye (2020), where a similar trend was noted, with larger farms having higher energy productivity due to optimized use of resources and mechanization of production processes.

In order to improve energy productivity in yam production, it is crucial to adopt optimized sizes of yam sett based on yield response to experimental data, improve miniset and vine cutting technology, improve nutrient management, and enhance weed and pest control measures to reduce yield losses, while initiating gradual mechanization of labour-intensive processes in yam production.

3.4.3 Energy ratio

Energy efficiency in yam production, defined by energy ratios, was found to be 3.78, 3.45, and 4.09 for small, medium, and large farms, respectively (Figure 6c). Energy ratios greater than one imply energetically efficient production in this study area. Using ANOVA, statistically significant differences ($p < 0.05$) in energy ratios among farm sizes were established. Further post hoc analysis of mean differences showed that large farms had significantly higher energy ratios compared to small farms, with a progressive increase in energy ratios with farm size, suggesting a better utilization of energy in larger farms. Higher energy ratios in medium and large farms could be attributed to efficient fertilizer application, better utilization of biological inputs per unit yield, better coordination in farm operations, and slightly higher yields.

Lower energy ratios in small and medium farms could be attributed to inefficient use of inputs such as excessive fertilizer application and suboptimal sett size selection. This is in agreement with the findings of Adeyeye et al. (2024) and Ismail and Mahmud (2023), who found inefficient use of inputs in yam production by Nigerian farmers. Energy ratios in this study are lower compared to 7.01 in cassava production by Bamgboye and Kosemani (2015) and this is attributed to lower biological energy requirement in cassava, which is 3,029.6 MJ ha⁻¹, compared to over 9,000 MJ ha⁻¹ in this study.

To enhance energy ratios in yam production, there is a need to employ precision agriculture technology in fertilizer application, organic fertilizer use to reduce chemical application, and optimization of sett weights to balance yield with energy inputs.

3.4.3 Agrochemical energy ratio

The agrochemical energy ratios were found to be 46.28, 46.46, and 46.38% for small, medium, and large farms, respectively (Figure 6(d)). Unlike other parameters, ANOVA results revealed no significant differences between farm categories ($p > 0.05$). This may be an indication of similar fertilizer and herbicide application practices. The increased agrochemical energy ratio may be an indication of a strong reliance on synthetic materials. Excessive use of agrochemicals may have several environmental consequences, such as soil degradation, nutrient imbalance, groundwater contamination, and biodiversity loss. This study corroborates the findings of Owoicho et al. (2023), which revealed a positive relationship between heavy metals in yam tubers from Benue State and excessive use of agrochemicals during production and storage. Excessive use of fertilizers and herbicides may result in heavy metals accumulating in the soil, which may lead to environmental pollution and health hazards to humans and animals. In terms of sustainability, a reduced agrochemical energy intensity is desirable. Accordingly, it is recommended that farmers adopt integrated nutrient management, use bio-fertilizers, use biopesticides, adopt site-specific fertilizer application, and attend training program.

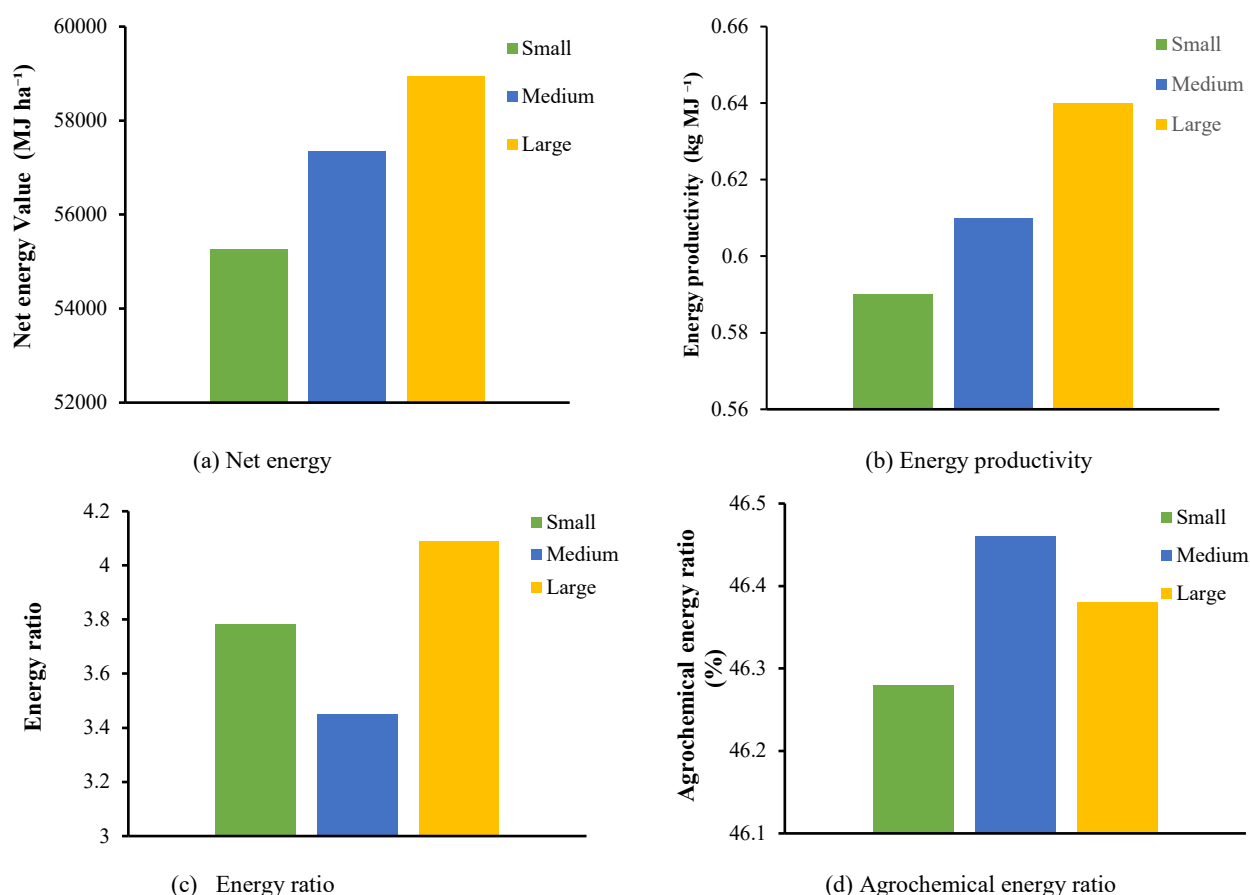


Figure 6 Energy indicators in yam cultivation

4 Conclusions

This study assessed the structure of energy consumption, patterns of energy use, and energy performance indicators in yam cultivation on small, medium, and large-scale farms in Benue State, Nigeria. The findings revealed that yam cultivation is a highly energy-consuming practice with total energy input ranging from 19,024.37 to 19,835.08 MJ ha⁻¹. The biological energy input in yam setts and chemical energy input in fertilizers and herbicides dominated the total energy input in yam cultivation on all farms, contributing more than 94% to the total energy input in yam cultivation. The operation-wise analysis revealed that the planting and fertilization operations were the most energy-consuming in yam cultivation, as indicated by the high biological energy input in yam setts and chemical energy input in fertilizers. The mechanical and thermal energy inputs were low in yam cultivation, as indicated by the low level of mechanization in yam cultivation in the study area.

The findings revealed that all farms had positive

net energy value and energy ratio higher than one, indicating that yam cultivation in the study area is energetically viable. The energy productivity and energy ratio increased with the size of farms; hence, yam cultivation on medium and large-scale farms in the study area is more efficient in input use and resource utilization compared to small-scale farms. The findings revealed that the energy performance indicators in yam cultivation in the study area were lower than in cassava cultivation in Nigeria due to the high biological energy input in yam setts used in yam cultivation.

The findings of this research identify key areas where energy use efficiency in yam production can be significantly enhanced. To this effect, optimal sett sizes, miniset technology, and other alternative propagation methods, precise application of fertilizers, and organic nutrient sources are likely to reduce biological and chemical energy use to a great extent. Furthermore, phased and targeted mechanization of labour-demanding activities is likely to enhance productivity without significantly increasing fossil

energy use.

Collectively, advances in seed system and nutrient management practices offer a powerful tool for sustainable, energy-efficient, and environmentally friendly yam production in Benue State. This is in addition to their likely benefits in enhancing energy use efficiency, reducing production costs, and addressing environmental concerns and food security in yam-dependent regions of the world.

References

- Adeyeye, M. O., Ojo, O. O., Olubunmi-Ajayi, T. S., and Oladosu, O. A. 2024. Optimizing resource-use efficiency of yam producers in Ondo State, Nigeria: A path to enhanced food production. *International Journal of Sustainable Social Science*, 2(2), 133–150. <https://doi.org/10.59890/ijsss.v2i2.1643>
- Ampofo, D., Agbenorhevi, J. K., Firempong, C. K., and Adu-Kwarteng, E. 2021. Glycemic index of different varieties of yam as influenced by boiling, frying and roasting. *Food Science and Nutrition*, 9(2), 1106–1111.
- Bamgboye, A. I., and S. O. Jekayinfa. 2006. Energy Consumption Pattern in Palm Kernel Processing Operations. *CIGR Eournal*, 8: EE05 013.
- Bamgboye, A. I., and B. S. Kosemani. 2015. Energy Input in the Production of Cassava. *Energy and Environment Research*, 5(1): 42-48.
- Bassey, E. E. 2017. Constraints and prospects of yam production in Nigeria. *European Journal of Physical and Agricultural Sciences*, 5(1): 55-64.
- Centre for Agriculture and Biosciences International (CABI). *Dioscorea Alata* (White Yam). Available at: <https://www.cabi.org/isc/datasheet/19293>. Accessed 5 December 2017.
- Demircan, V., K. Ekinici, H. M. Keener, D. Akbolat, and C. Ekinici. 2006. Energy and economic analysis of sweet cherry production in Turkey: A case study from Isparta province. *Energy Conversion and Management*, 47: 1761-1769.
- Eyinla, T. E., R. A. Sanusi, and B. Maziya-Dixon. 2022. Evaluation of *in vitro* and *in vivo* glycemic index of common staples made from varieties of white yam (*Dioscorea rotundata*). *Frontiers in Nutrition*, 9: 983212.
- Food and Agriculture Organization (FAO). 2018. FAOSTAT statistical database. Available at: <https://www.fao.org/faostat/>. Accessed 16 May 2021.
- FAOSTAT. 2013. Database. Available at: <Http://Bit.Ly/Nmqzzf>. Accessed 10 April 2014.
- FAOSTAT. 2022. Food and Agriculture Organization of the United Nations, Rome. Available at: <http://faostat3.fao.org/home/index.html#>. Accessed 1 November 2022.
- FAOSTAT. 2021. Yam production in west Africa, Food and Agriculture Organization. Available at: <http://www.fao.org/faostat/en/#data>. Accessed 15 October 2021.
- Fasusi, S. A., J. M. Kim, and S. Kang. 2022. Determinants and Constraints influencing Yam Production in Nigeria. *Journal of the Korean Society of Internaitonal Agriculture*, 34(4): 298-305.
- Imran, M., O. Özcatılbas, and M. K. Bashir. 2020. Estimation of energy efficiency and greenhouse gas emission of cotton crop in South Punjab, Pakistan. *Journal of the Saudi Society of Agricultural Sciences*, 19(3): 216-224.
- International Institute for Tropical Agriculture (IITA). 2009. Yam (*Dioscorea* Species). IITA Annual Report. Available at: <Http://www.Iita.Org/Yam>. Accessed 15 March 2014.
- Ismail, U. O. and Mahmud, H. U. 2023. Determinant factors of technical efficiency in yam production in Moro LGA, Kwara State, Nigeria. *Journal of Agriprenurship and Sustainable Development*, 6(2), 1–8. <https://doi.org/10.59331/jasd.v6i2.428>
- Jekayinfa, S. O., K. M. Adeleke, C. A. Ogunlade, B. F. Sasanya, and N. A. Azeez. 2022. Energy and exergy analysis of Soybean production and processing system. *Cleaner Engineering and Technology*, 10: 100540.
- Kosemani, B. S., and A. I. Bamgboye. 2020. Energy input-output analysis of rice production in Nigeria. *Energy*, 207: 118258.
- Kosemani, B. S., and A. I. Bamgboye. 2021. Modelling energy use pattern for maize (*Zea mays* L.) production in Nigeria. *Cleaner Engineering and Technology*, 2: 100051.
- Maikasuwa, M. A., and A. L. Ala, 2013. Determination

- of profitability and resource-use efficiency of yam production by women in Bosso Local Government Area of Niger State, Nigeria. *European Scientific Journal*, 9(16): 196-205.
- Merem, E. C., Y. A. Twumasi, S. Fageir, D. Olagbegi, J. Wesley, R. Coney, Y. Babalola, T. Thomas, A. Hines, G. Hirse, G. S. Ochai, E. Nwagboso, M. Crisler, S. Leggett, J. Offiah, and S. Emeakpor. 2024. Exploring Shifts in Yam Production Trends Along Nigeria's Southern Region. *International Journal of Food Science and Nutrition Engineering*, 14(1): 1-22.
- Mudioppe, J., D. I. Coyne, E. Adipala, and H. A. Talwana. 2012. Damage to yam (*Dioscorea* spp.) by root-knot nematode (*Meloidogyne* spp.) under field and storage conditions in Uganda. *Nematropica*, 42:137-145.
- Nabavi-Pelesaraei, A., and A. Damgaard. 2023. Regionalized environmental damages and life cycle cost of chickpea production using LC-IMPACT assessment. *Environmental Impact Assessment Review*, 103: 107259.
- Nabavi-Pelesaraei, A., Z. Saber, F. Mostashari-Rad, H. Ghasemi-Mobtaker, and K. W. Chau. 2021. Coupled life cycle assessment and data envelopment analysis to optimize energy consumption and mitigate environmental impacts in agricultural production. In *Methods in Sustainability Science: Assessment, Prioritization, Improvement, Design and Optimization*, ed. J. Ren, ch. 14, 227–264. Amsterdam, Netherlands: Elsevier Inc.
- Nia, A. S., M. G. Parashkoohi, D. M Zamani, and H. Afshari. 2024. Optimization of energy use efficiency and environmental assessment in soybean and peanut farming using the imperialist competitive algorithm. *Environmental and Sustainability Indicators*, 22: 100361.
- Nwosu, C. S., and V. B Okoli. 2010. Economic Analysis of Resource Use by Wase Yam Farmers in Owerri Agricultural Zone of Imo State, Nigeria. In *Proc. of the 44th Annual Conference of Agricultural Society of Nigeria*, 29-34. Oyo State, Nigeria, 18-22 October.
- Olatoye, K. K., R. Akinoso, A. I .Lawal, and K. A. Babalola. 2013. A Comparative Study of Energy Demand of Instant- Pounded Yam Flour Production Methods. *Journal of Energy Technologies and Policy*, 4(3): 14-18.
- Olubunmi-Ajayi, T. S., T. T. Amos, E. A. Borokini, and O. A. Aturamu. 2023. Profitability and technical efficiency of maize-based cropping system farmers in Ondo State, Nigeria. *International Journal of Agricultural Science, Research and Technology in Extension and Education Systems*, 13(1): 11-22.
- Olutumise, A. I. 2020. Transportation System and Output Market Participation Nexus among Yam Producers in Southwest Region of Nigeria. *Scientific Paper Series Management, Economic Engineering in Agriculture and Rural Development*, 20(4): 365 – 379.
- Owoicho, H. A., F. J. Ikpa, C. C. Iheukwumere, and R. A. I. Ega. 2023. Heavy metal contamination of yams produced in benue state. *Wukari International Studies Journal*, 7(3): 88-102.
- Ozkan, B., R. F. Ceylan, and H. Kizilay. 2011. Comparison of energy inputs in glasshouse double crop (fall and summer crops) tomato production. *Renewable Energy*, 36(5): 1639–1644.
- Rashidi, K., A. Azizpanah, R. Fathi, and M. Taki. 2024. Efficiency and sustainability: Evaluating and optimizing energy use and environmental impact in cucumber production. *Environmental and Sustainability Indicators*, 22: 100407.
- Sharifi Nia, A., Gholami Parashkoohi, M., Mohammad Zamani, D., and Afshari, H. 2024. Optimization of energy use efficiency and environmental assessment in soybean and peanut farming using the imperialist competitive algorithm. *Environmental and Sustainability Indicators*, 22, 100361. <https://doi.org/10.1016/j.indic.2024.100361>
- Shehu J. F., J. T. Iyortyer, S. I. Mshelia, and A. A. U. Jongur., 2010. Determinants of Yam Production and Technical Efficiency among Yam Farmers in Benue State, Nigeria. *Journal Social Science*, 24(2): 143-148.
- Simpeh, E. K., J. G. Pillay, R. Ndiokubwayo, and D. J. Nalumu. 2022. Improving energy efficiency of HVAC systems in buildings: a review of best practices. *International Journal of Building Pathology and Adaptation*, 40(2): 165–182.

- Singh, H., D. Mishra, and N. M. Nahar. 2002. Energy use pattern in production agriculture of typical village in arid zone, India. *Energy Conversion & Management*, 43: 2275-2286.
- Singh, S., and J. P. Mittal. 1992. *Energy in Production Agriculture*. New Delhi, India: Mittal Publications.
- Statista. 2019. Doris Dokua Sasu, in Ten major crops in Nigeria. Available at: <https://www.statista.com/statistics/1135550/ten-major-crops-in-nigeria/>. Accessed 8 November 2022.
- Strapatsa, A. V., G. D. Nanos, and C. A. Tsatsarelis. 2006. Energy flow for integrated apple production in Greece. *Agriculture Ecosystems & Environment*, 116(3-4): 176-180.
- Sugihara, Y., K. Darkwa, H. Yaegashi, S. Natsume, M. Shimizu, A. Abe, A. Hirabuchi, K. Ito, K. Oikawa, M. Tamiru-Oli, A. Ohta, R. Matsumoto, P. Agre, D. De Koeyer, B. Pachakkil, S. Yamanaka, S. Muranaka, H. Takagi, B. White, R. Asiedu, H. Innan, A. Asfaw, P. Adebola, and R. Terauchi. 2020. Genome analyses reveal the hybrid origin of the staple crop white Guinea yam (*Dioscorea rotundata*). *Proceedings of the National Academy of Sciences*, 117(50): 31987-31992.
- Tabatabaie, S. M. H., Rafiee, S., Keyhani, A., & Heidari, M. D. 2013. Energy use pattern and sensitivity analysis of energy inputs and input costs for pear production in Iran. *Renewable Energy*, 51, 7–12. <https://doi.org/10.1016/j.renene.2012.08.077>
- Taghavifar, H., and A. Mardani. 2015. Energy consumption analysis of wheat production in West Azarbayjan utilizing life cycle assessment (LCA). *Renewable Energy*, 74: 208–213.
- Umar, A. G, M. S. Nwafor, S. Likita, and S. Adoko. 2006. The Indigenous yam storage technology and post-harvest losses in Nigeria. The Benue State perspective. *International Journal of Food and Agricultural Research*, 5(2): 113-139.