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Energy budgeting and life cycle assessment of cashew cultivation under different planting densities

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ABSTRACT

Energy budgeting is important for determining the sustainability and vulnerability of a crop production system. In the present study, an assessment of the energy requirements for cashew cultivation under three different planting densities was carried out during 2015-20. The study revealed that the total input energy consumption for cashew cultivation ranged from 75292.68 to 120903.58 MJ/ha. The energy productivity from 0.04 to 0.13 kg/MJ and energy use efficiency varied from 8.46 to 24.61% under three planting densities. The highest energy was consumed in terms of chemical fertilizers for all the planting densities followed by fuel (diesel), machinery, farmyard manure (FYM), pesticides, petrol and human energy. The analysis revealed the need to implement improved management practices to enhance the energy efficiency by reducing the energy consumption in inputs, by optimizing energy consumption and/or improving the crop yield by optimizing the cultivation methods and switching from non-renewable sources to renewable sources of energy. Among the three different planting densities, 2.5x2.5 m spacing consumed the highest energy followed by 5x5 m and 7.5x7.5m spacing. However, the planting density of 2.5x2.5 m spacing was more energy efficient over the years due to more yields per unit area.

Introduction

Cashew (*Anacardium occidentale* L.) is a nut crop native to Brazil. Currently, cashew is cultivated in over 30 countries and has emerged as a potential foreign-exchange earning crop in the developing countries. Cashew is good source of carbohydrates (22%), proteins (21%), fat (47%) and minerals (calcium, iron and phosphorous) (Sharma, 2004) and offers 575 kcal of energy per 100 g (Sathe, 1994). Historically India dominated the global cashew market (Nayak and Savadi, 2019) (Anonymous, 2014). Currently, Vietnam, India and Ivory Coast are the major cashew producers in the world (FAOSTAT, 2018). Cultivation of cashew in India is mainly confined to the coastal areas and in recent times it has been spread to plains of Chhattisgarh, Jharkhand and hills of the North Eastern States. Energy is the basic driver of agricultural crop production and practices (Ozkan *et al*., 2004). Limited agricultural land availability due to urbanization has necessitated the need for intensive agriculture. The success of sustainable agriculture depends on the utilization of energy

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sources in an efficient manner (Fadavi *et al*., 2011). For agriculture, the energy needs are split into two categories, viz. direct and indirect. The crop production activities such as land preparation, irrigation, weeding, harvesting, and threshing and transportation of various inputs for agricultural production come under the direct energy category (Singh, 2000). The energy for activities such as packaging of agricultural produce and transportation of the seeds, fertilizers, farm machines, insecticides and pesticides are regarded as indirect energy. Yet another classification of the energy is as non-renewable or renewable energy sources based on the capability of being renewed (Rajesh *et al*., 2018).

An energy assessment of the crop production system and practices is required to determine the optimal energy input for achieving different productivity levels. Minimizing or combining machinery operations may minimize the energy input, time and labour (Esengun *et al*., 2007; Karale *et al*., 2008). Analysis of energy involved in agricultural production is often used as the basic components for life cycle assessments. (Piringer & Steinberg, 2006). Several investigations have been done on energy usage in different agricultural systems including fruit and nut crops (Strapatsa *et al*., 2006; Demircan *et al*., 2006; Fadavi *et al*., 2011; Paramesh *et al*., 2018; Bartzas and Komnitsas, 2018). The energy indicators and the energy expenditure per unit of apple production was estimated in West Azarbaijan, Iran by Fadavi *et al*. (2011). The values of energy productivity, net energy and output-input energy were estimated to be 101.50 MJ/ha, 0.23 kg/MJ, –56.32 MJ/ha and 0.44, respectively. The study findings indicated that 96.7% of total energy input was in the form of non-renewable sources. Hatirli *et al*. (2006) analysed the correlation between energy inputs and crop yields for greenhouse tomato cultivation in Turkey and developed an economic model. Likewise, in sweet cherry production, Demircan *et al*. (2006) showed that the fertilizers (45.35%) were the foremost energy-consuming input source followed by diesel oil (21.53%). In pistachio production, the total energy intake under irrigated conditions in Greece was found to be 41.9 GJ/ha, while the ratio of energy productivity and energy efficiency rate was 0.06 kg/MJ and 70%, respectively (Bartzas and Komnitsas, 2018). Paramesh *et al*. (2019) reported an improved energy efficiency of 1.72 and net energy of 19625 MJ/ha under the organic nutrient management due to lower energy intake (30722MJ/ha) and higher energy output (50347MJ/ha), compared to the no-manuring and integrated nutrient management practices.

In India, cashew is generally grown as rainfed crop under wider spacing of 7.5 x 7.5 m with 178 trees per hectare. However, under wider spacing system, the plants take 7-8 years to cover the allotted space as a result the resources such as land, sunlight, chemical inputs *etc* go wasted (Nayak *et al*., 2019). The adoption of high density and ultra-density planting systems in cashew helps to utilise the land and input resources more effectively in the initial years of plantation establishment and as consequence, increased productivity per unit area. The energy budgeting in cashew production systems has received little attention and there are no reports energy budgeting in cashew. The present study was undertaken to find out the energy requirement and life cycle assessment of cashew cultivation under different planting densities in coastal India. This is first report of energy budgeting in cashew crop production, which can facilitate effective utilization inputs and energy resource to attain better productivity with little energy wastage and environmental damage.

Material and Methods

Experimental site

The investigation was carried out at the ICAR-Directorate of Cashew Research Puttur, Karnataka, India. The study area has hot and humid climate with annual average precipitation of 3500 mm and the soil is sandy clay loam with a pH of 5.25. The present study was conducted from 2015 to 2020 to assess the life cycle and energy budgeting of cashew cultivation under three planting densities [2.5 x 2.5 m, 5 x 5 m and 7.5 x 7.5 m] under rainfed condition. The experiment was designed in a randomized block design (RBD) with three replications. The jumbo nut cashew hybrid, H-130, a pruning responsive cultivar planted during 2013 at the three different spacings was chosen for the study.

Computation of parameters

The energy assessment was carried out on the basis of various farm operations (planting, weeding, harvesting) as well as on the direct (human labour and fuel) and indirect (farm machines, chemical fertilizers and pesticides) energy resources used in the crop production process. Information on the duration, quantity and frequency of the unit operations and energy inputs was collected and quantified using the energy coefficient in order to estimate energy usage in a particular unit operation (Table 1).

Table 1: Resource input, outputs, and their energy equivalents

Input	Energy Equivalent	Unit	Reference
Human labour	1.96	MJ/man h	Paramesh *et al.* (2019); Erdal *et al.* (2007); Nassiri & Singh (2009); Mohammadi *et al.* (2008)
Machinery	62.7	MJ/kg	Paramesh *et al.* (2019); Mohammadi *et al.* (2008); Singh & Mittal (1992); Gündoğmuş (2006)
FYM	0.3	MJ/kg	Paramesh *et al.* (2019); Taki *et al.* (2012); Hatirli *et al.* (2006); Demircan *et al.* (2006)
Fertilizers			
N	60.6	MJ/kg	Singh & Mittal (1992); Gündoğmuş (2006)
P	11.1	MJ/kg	Singh & Mittal (1992); Gündoğmuş (2006)
K	6.7	MJ/kg	Singh & Mittal (1992); Gündoğmuş (2006)
Chemicals			
Insecticide	184.63	MJ/kg	Pimentel (1980)
Petrol	48.23	MJ/l	Singh & Mittal (1992)
Diesel	56.31	MJ/l	Paramesh *et al.* (2019); Gündoğmuş (2006); Mohammadi *et al.* (2008)
Self-Propelled Machines	68.4	MJ/kg	Singh & Mittal (1992)
Cashew fruit	1.9	MJ/kg	Singh & Mittal (1992)

The methodology adopted for the analysis for assessing the energy inputs used in cashewnut production is as follows.

1. The use of human energy was calculated by taking into account the time of labour-intensive activity and the total number of people involved in that particular farm operation. The gross human energy expenditure was estimated by multiplying the energy coefficient of the human power for unit man-hour by the total number of hours of human activity in the particular unit operation (Sharma *et al*., 2020).
2. In the case of the tractor, diesel engine or other machinery, the volume of fuel used for a specific field operation was determined using the top-fill method. The energy consumption to manufacture machineries such as tractors, weeders and other farm equipment was determined based on their weight, useful life and average annual working hours.
3. The quantity of input materials like farmyard manure (FYM), chemical fertilizers and insecticides/pesticides utilized in cashew production has been converted to energy equivalent by multiplying the amount of the input material used in the plots with the energy content of each input sources(Azam & Singh, 1996; Khan & Singh, 1997).

In the present study, useful life and average annual working hours were used as perIS:9164 (1979). The following equation was used to calculate the energy expenditure from farm machines (Rajesh *et al.*, 2018).

$$\mathbf{E_M = (E_{qm} \times W_m \times W_{hm}) / (L_m \times W_{hym})} \quad (1)$$

Where,
E_M = Energy from farm machines
E_{qm}= Energy equivalent for machinery
W_m= Weight of machine
W_{hm}= Machine working hours
L_m= Life of machine
W_{hym}= Machine working hours/year

Energy indicators

The identified set of indicators was calculated based on the energy equivalents of inputs and outputs to determine the energy efficiency as follows (Balogh & Hall, 2016; Hall, 2011; Martin *et al*., 2014; Mohammadi & Omid, 2010; Singh *et al*., 1997).

Energy use efficiency

The energy use efficiency shows the effectiveness of a crop production system. It is important to remember that the energy consumed in input can be minimized by optimizing energy consumption or to increase the crop yield by optimizing farming practices in order to enhance energy use efficiency during the cultivation cycle.

$$\text{Energy use efficiency} = \frac{\text{Total energy output (MJ/ha)}}{\text{Total energy input (MJ/ha)}} \quad (2)$$

Net energy

Net energy is one of the key performance indices that show the relationship between the gross energy produced from the main and by-product and the total input energy required for crop production.

$$\text{Net Energy} = \text{Energy output (MJ/ha)} - \text{Energy input (MJ/ha)} \quad (3)$$

Energy productivity

It defines the amount of product obtained per unit of input energy used. The input energy sources like human labour and FYM comes under renewable energy sources; while non-renewable energy consists of energy inputs from machines, fuel, chemical fertilizers and chemicals.

$$\text{Energy productivity} = \frac{\text{Crop yield (kg/ha)}}{\text{Total energy input (MJ/ha)}} \quad (4)$$

Specific energy

This index represents how much of energy is used by a product to produce 1 kg and is typically used to compare various product categories. The entire crop production process is more effective when the specific energy is less.

$$\text{Specific energy} = \frac{\text{Total energy input (MJ/ha)}}{\text{Crop yield (kg/ha)}} \quad (5)$$

Results and discussion

Analysis of input-output energy use for cashew production and energy indicators

The total energy expenditure and different energy indices for the production of cashew at 2.5 x 2.5 m spacing showed that the overall energy used in various unit operations in cashew production was 120903 MJ/ha (Table 2). The maximum energy intake was utilized by chemical fertilizers (55788 MJ/ha) followed by the fuel (diesel) (27479 MJ/ha) (Table 2). The fuel energy (diesel oil) was used mainly to run earth moving machines for the initial land development activities. Therefore, exact chemical fertilizer management, taking the amount and frequency of fertilization into account, as well as proper selection and management of machinery to reduce direct use of diesel fuel are required to save non-renewable energy sources without compromising the yield or profitability and to increase the energy use efficiency of cashew production. Proebsting (1980) estimated that the energy expenditure for fuel (diesel oil) was 14.87% and 14.75% of the overall energy intake for the red tart and sweet cherry respectively. The energy consumption for machinery, farmyard manure (FYM) chemicals, petrol and human energy were found to be 22405, 6000, 5760, 1746 and 1724 MJ/ha, respectively.

A cashew tree starts bearing two years after planting in closer spacing but widely spaced planting takes six to seven years for commercial production. The energy efficiency, specific energy, energy productivity and net energy of cashew production were also estimated for 2.5x2.5 m spacing (Table 2). The mean yield of cashew crop was determined to be 1248 kg/ha in the second year and it was significantly increased to 2432 kg/ha during the fourth year. The energy ratio (also known as energy use efficiency) varied from 12.2 to 24.6% in the cashew orchards, showing the ineffective utilization of energy in the cashew production. It is important to note that the proportion can be maximized by enhancing the crop yield (the cashew apple energy coefficient is relatively less) and/or by reducing input energy expenditure (input management). The specific energy for cashew production varied from 8.22 to 4.06 MJ/kg. The study findings showed that energy productivity and net energy varied from 0.06 to 0.13 kg/MJ and -17,126.66 to -14,158.49 MJ/ha respectively. This means an average output of 0.10 units per unit of energy was achieved. The net energy calculated was negative inferring that in cashew production, the energy was wasted. Fadavi *et al.* (2011) observed that net energy and energy productivity for apples were –64,556 MJ/ha and 0.19 kg/MJ, respectively. The net energy of tangerine (-8201 MJ/ha) and plum (-116,219 and -125,788 MJ/ha) was reported by

Table 2: Energy consumption and different energy indices for cashew production (2.5 x 2.5 m spacing)

Inputs	Total Energy Equivalent (MJ/ha)					Total Energy MJ/ha	Percentage of total energy input (%)
	Initial establishment	I Year	II Year	III Year	IV Year		
Human labour	295.96	226.07	339.72	451.02	411.45	1724.22	1.43
Machinery	22366.80	16.11	13.45	4.48	4.48	22405.33	18.53
FYM	1200	1200	1200	1200	1200	6000.00	4.96
Chemical fertilizer	914.64	9977.62	14965.37	14965.37	14965.37	55788.38	46.14
Insecticides	354.49	1683.83	1240.71	1240.71	1240.71	5760.46	4.76
Petrol		964.6	781.326			1745.93	1.44
Diesel	23650.2	957.27	957.27	957.27	957.27	27479.28	22.73
Total Energy Consumption	48782.09	15025.49	19497.86	18818.86	18779.29	120903.58	100.00
Yield (kg/ha)			1248	2240	2432	5920	
Total Energy output (MJ/ha)			2371.2	4256	4620.8	11248.00	
Energy use efficiency (%)			12.16	22.62	24.61	9.30	
Specific energy (MJ/kg)			8.22	4.42	4.06	10.75	
Energy productivity (kg/MJ)			0.06	0.12	0.13		
Net energy yield (MJ/ha)			-17126.66	-14562.86	-14158.49	-109655.58	

FYM: Farm yard manure

Mohammadshirazi *et al.* (2012), and Tabatabaie *et al.* (2012). The low energy output may be due to the low yields during the second year and higher energy consumption during the initial establishment of cashew orchard (less output, with increased input). The different inputs utilized in cashew production and their energy coefficients; output energy equivalents and energy indicators are represented in Table 3. The overall energy equivalent of inputs was determined to be 98532 MJ/ha. Out of total energy input, energy from human labour accounts for 1021.32 MJ/ha whereas machinery, FYM, chemical fertilizers, chemicals petrol and diesel energy were found to be 14738.71, 4200.00, 55788.86, 2570.05, 2749.11 and 17463.98 MJ/ha, respectively. It was observed that in cashew production much energy was consumed from fertilizers followed by the fuel energy (diesel oil) and farm machines. The energy inputs utilized in production such as FYM, fuel, chemicals (insecticide/pesticide) and human labour were considered to be comparatively less than the other inputs. The average yield of cashew under 5 x 5m spacing varied from 880 to 1212 kg/ha and its energy value was found to be 1672 to 2302MJ/ha. The calculated mean values of energy productivity and energy use efficiency varied from 0.05 to 0.07 kg/MJ and 9.32 to 12.95 %, respectively. These findings suggest that there is considerable potential in the study region for improving the energy efficiency of cashew production. Energy efficiency was different from other orchard plants like cherry (0.96) (Kizilaslan, 2009) and apple (0.97) (Hasanzadeh & Rahbar, 2005) due to the different growth rates and phenology of the crops and operations involved in the crop production. The calculation of energy productivity for various crops such as potato (0.35) (Mohammadi *et al*., 2008) and cherry (0.51) (Kizilaslan, 2009) is well documented. The average specific energy of cashew production at 5 x 5 m spacing varied 10.73 to 7.72 MJ/kg, indicating that per unit of cashew production, an average of 9.07 MJ of energy was ingested. The findings revealed that net energy varied from -16275.00 to -15482.18 MJ/ha. The net energy calculated is negative inferring that more energy is consumed during the cashew production. Similarly, Fadavi *et al*. (2011) found that net energy for apple production was about –64,556 MJ/ha while the energy productivity was 0.19 kg/MJ.The unit operation wise energy requirements in cashew production under wider spacing of 7.5 x 7.5 m were monitored and evaluated for studying different patterns of energy usage and results are reported in Table 4. Out of all the energy inputs, chemical fertilizer application recorded the largest energy usage among the input variables used in cashew production, reaching 42215 MJ/ha (56.07%) in overall energy expenditure. The

Table 3: Energy consumption and different energy indices for cashew production (5 x 5 m spacing)

Inputs	Total Energy Equivalent (MJ/ha)					Total Energy MJ/ha	Percentage of total energy input (%)
	0 Year	I Year	II Year	III Year	IV Year		
Human labour	137.20	145.04	237.14	261.41	240.54	1021.32	1.04
Machinery	14698.18	18.29	16.63	2.80	2.80	14738.71	14.96
FYM	600	600	600	1200	1200	4200.00	4.26
Chemical fertilizer	914.64	9978.11	14965.37	14965.37	14965.37	55788.86	56.62
Chemicals	88.62	465.27	465.27	775.45	775.45	2570.05	2.61
Petrol		1446.9	1302.21			2749.11	2.79
Diesel	15541.56	360.384	360.384	600.83	600.83	17463.98	17.72
Total Energy Consumption	31980.21	13013.99	17947.00	17805.86	17784.98	98532.04	100.00
Yield (kg/ha)			880	1068	1212	3160	
Total Energy output (MJ/ha)			1672	2029.2	2302.8	6004.00	
Energy use efficiency (%)			9.32	11.40	12.95	6.09	
Specific energy (MJ/kg)			10.73	8.77	7.72	16.41	
Energy productivity (kg/MJ)			0.05	0.06	0.07		
Net energy yield (MJ/ha)			-16275.00	-15776.66	-15482.18	-92528.04	

Table 4: Energy consumption and different energy indices for cashew production (7.5 x 7.5 m spacing)

Inputs	Total Energy Equivalent (MJ/ha)					Total Energy MJ/ha	Percentage of total energy input (%)
	0 Year	I Year	II Year	III Year	IV Year		
Human labour	97.06	128.62	188.93	197.62	205.48	817.71	1.09
Machinery	12429.55	16.36	17.33	1.24	1.24	12465.71	16.56
FYM	265.5	265.5	265.5	531	531	1858.50	2.47
Chemical fertilizer	545.79	5952.39	8929.02	11905.19	14882.87	42215.26	56.07
Chemicals	38.77	206.79	206.79	341.57	341.57	1135.47	1.51
Petrol		1360.086	1446.9			2806.99	3.73
Diesel	13142.75	159.3573	159.3573	265.7832	265.7832	13993.04	18.58
Total Energy Consumption	26519.42	8089.10	11213.83	13242.39	16227.94	75292.68	100.00
Yield (kg/ha)			499.14	663.75	723.93	1886.82	
Total Energy output (MJ/ha)			948.366	1261.125	1375.467	3584.96	
Energy use efficiency (%)			8.46	9.52	8.48	4.76	
Specific energy (MJ/kg)			11.82	10.50	11.80	21.00	
Energy productivity (kg/MJ)			0.04	0.05	0.04		
Net energy yield (MJ/ha)			-10265.46	-11981.27	-14852.47	-71707.72	

second-largest contribution to energy consumption was the use of diesel energy (13993.04 MJ/ha) followed by machinery (12465.71 MJ/ha). Diesel oil is primarily used for operating earth moving machines and tiller operated sprayers engaged in different farming activities such as land preparation and spraying of plant protection chemicals. The share of electricity was only 2806.99 MJ/ha (3.73% of the overall energy intake). The FYM contributed 2.47%, while chemicals and human labour contributed even less i.e., 1.51% and 1.09%, respectively. The various energy indicators *viz*., energy use efficiency, specific energy, energy productivity and net energy were determined based on the energy output from the cashew (Table 4). The calculated average energy use efficiency and energy productivity values varied from 8.46 to 9.52% and 0.04 to 0.05 kg/MJ respectively. Energy productivity is low compared to the results reported in other fruits such as apricot (0.24 kg/MJ) (Esengun *et al*., 2007), and apple (0.49 kg/MJ)(Rafiee *et al*., 2010). It implies that extra energy should be spent to increase the crop yield. It was also observed that energy consumption has a positive correlation with crop yield. Specific energy shows the amount of energy spent to produce a unit of product. It was slightly higher (11.82 to 10.50 MJ/kg). Bartzas and Komnitsas (2018) found that the average specific energy of pistachios production was 16.97 MJ/kg, implying that 16.97 MJ of energy was consumed in pistachios for the production per unit of dry in-shell pistachios. The net energy in cashew production system varied from -14852.47 to -10265.46 MJ/ha indicating that the present production system is not energy efficient.

In this study, the total energy expenditure in cashew production for different plant densities during 4 years in coastal India was assessed and presented in Table 5. The calculated energy consumption for different plant densities varied from 75292.68 to 120903.58 MJ/ha.

The study showed that energy consumption in cashew production increases with an increase in the number of plants per unit area. The energy use efficiency gap recommends improving the crop yield by optimizing the farming practices or minimizing the input energy utilized by optimizing energy consumption. In cashew production, chemical fertilizer is one of the most significant energy input sources followed by diesel oil and machinery. Therefore, we need to focus more on efficient use of chemical fertilizers, fuel (diesel) for various operations and energy for different machinery to reduce energy expenditure in cashew production compared to other factors. Special crop management practices and application procedures should be followed to minimize the inputs. Mangalassery *et al*. (2019) reported the biomass generated in mature cashew plantation can be converted to compost with 65% recovery and about 50% of the nutrient requirement of cashew plantation can be met by proper recycling of biomass generated in cashew plantations (Mangalassery *et al*., 2019; Rupa, 2017). Other means for reducing the reliance on chemical fertilizers without compromising on soil quality is to go for green manuring, application of bio fertilizers and organic farming (Kalaivanan & Rupa, 2017; Yadukumar *et al*., 2008). Proper management of critical inputs can reduce energy use on cashew production and can improve energy efficiency.

Table 5: Total energy equivalents (MJ/ha) in 4 years under different plant densities

Inputs	Spacing (m)		
	2.5 x 2.5	**5 x 5**	**7.5 x 7.5**
Human labour	1724.22	1021.32	817.71
Machinery	22405.33	14738.71	12465.71
FYM	6000.00	4200.00	1858.50
Chemical fertilizer	55788.38	55788.86	42215.26
Chemicals	5760.46	2570.05	1135.47
Petrol	1745.93	2749.11	2806.99
Diesel	27479.28	17463.98	13993.04
Total Energy Consumption (MJ/ha)	120903.58	98532.04	75292.68
Yield (kg/ha)	5920.00	3160.00	1886.82
Total Energy output (MJ/ha)	11248	6004	3584.958
Energy use efficiency	9.30	6.09	4.76
Specific energy (MJ/kg)	10.75	16.41	21.00
Energy productivity (kg/MJ)	0.05	0.03	0.03
Net energy yield (MJ/ha)	-109655.58	-92528.04	-71707.72

Source-wise Energy Distribution Pattern

The percentage shares of total input energy for cashew production for 2.5x2.5m spacing are depicted in Figure 1. The energy expenditure of fertilizers ranked first among the energy inputs and accounted for 46 percent followed by diesel (23%) and machinery (19%). The contribution of farmyard manure (5%), chemicals (5%), petrol (1%) and human energy (1%) remained at a low level. In order to bring down the energy consumption in cashew production the management of input consumption is more important. Among the overall

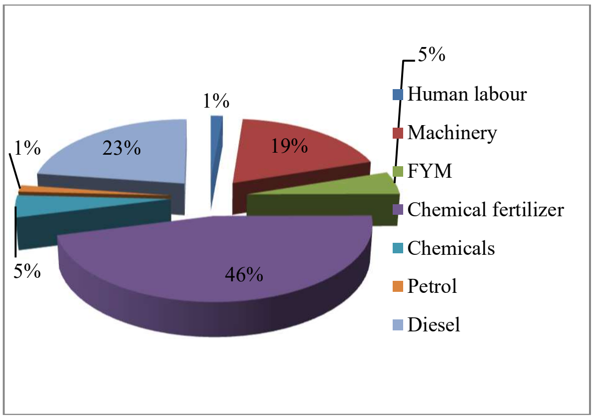

Figure 1: Percentages of total energy input for cashew production (2.5 x 2.5 m spacing)

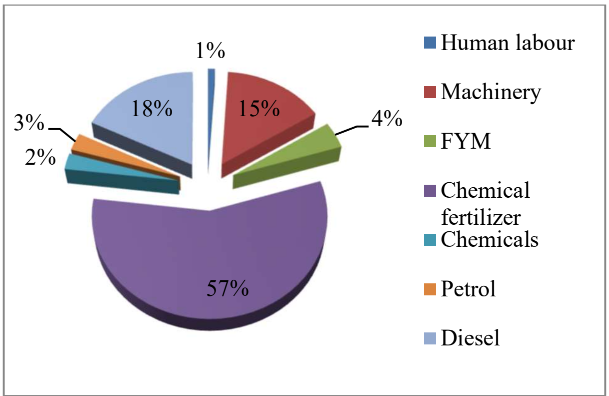

Figure 2: The anthropogenic energy inputs in the production of cashew (5 x 5 m spacing)

energy utilized, 25.60% was direct energy and 74.40% was indirect energy sources whereas, non-renewable form and renewable form of energy sources were recorded as 93.61% and 6.39%, respectively (Table 6). It was also noted that the impact of indirect energy was proved to be more effective than compared to direct energy sources. Hatirli *et al*. (2006) observed the effect of indirect energy's on yield was more significant than direct energy's. Hatirli *et al*. (2005) also observed a greater impact of non-renewable energy sources on crop yield compared to renewable sources.

In 5 x 5 m spacing, the energy consumption by crop management accounted for 57% of overall energy usage (Figure 2). The increased energy inputs used in the management of crops are due to the higher energy content of fertilizers. The fuel (diesel) energy has ranked second place in energy consumption accounting for about 18.0% of the overall input energy followed by energy from machinery (15 %). However, energy from FYM, chemicals, petrol and human labour consumed about 4, 2, 3 and 1%of the overall input energy respectively. Similarly, in ultra-density planting (2.5 x 2.5 m spacing), the indirect energy (77297.62 MJ/ha), sources were much greater in cashew production contrast to direct energy (21234.42 MJ/ha). The indirect energy input persisted at 78.45% of the total energy input compared with 21.60% of the direct energy. There was greater consumption of non-renewable sources (94.7%) than renewable form (5.3%) (Table 6). Consumption of both non-renewable sources and renewable sources of energy varied with various inputs used in crop production. The decrease in the usage of non-renewable sources has a direct impact on the cultivation cost. The non-renewable energy component is high in cashew production. The maximum contribution of non-renewable energy sources comes from the use of fertilizers, diesel, farm machines, chemical and petrol. The findings of the energy distribution in the present study are in close agreement with reports of Bartzas and Komnitsas (2018) for the production of irrigated pistachio and they also reported non-renewable sources and indirect energy sources accounts for about 81% and 66% of the overall energy expenditure.Source-wise energy analysis for cashew production at normal planting system (7.5 x 7.5 m) showed that the chemical fertilizers took a larger share of energy consumption (55.6% of overall energy intake), followed by diesel energy (19% of overall energy intake) (Figure3). The contribution of energy from machinery sources was determined to be 17% of the total energy requirements. However, energy sources like FYM,chemicals, petrol and human labour consumed about 2, 1, 4 and 1% of the total input energy. Under normal planting system, 93.45% and 76.60% of the overall input energy utilized for cashew production is non-renewable energy and indirect energy sources whereas, the amount of renewable and direct energy sources was found to be 3.55 and 23.40%, respectively (Table 6). Similar results were observed by Afshar *et al*. (2013) for pistachio production in irrigated condition and showed 86 % of total energy consumption for non-renewable energy sources. Likewise, the distribution of sources of energy has been recorded in several other fruit tree production, like apple (Fadavi *et al*., 2011) and almonds (Beigi *et al*., 2016).

Table 6: Quantification of various energy sources under different plant densities

SN	Energy Sources	Unit	Total energy consumption for different plant density (MJ/ha)		
			2.5 x 2.5	5 x 5	7.5 x 7.5
1.	Direct Energy (DE)	MJ/ha	30949.42 (25.60%)	21234.42 (21.55%)	17617.73 (23.40%)
2.	Indirect Energy (IDE)	MJ/ha	89954.16 (74.40%)	77297.62 78.45%)	57674.95 76.60%)
3.	Renewable Energy (RE)	MJ/ha	7724.21 (6.39%)	5221.323 (5.30 %)	2676.205 (3.55%)
4.	Non-Renewable Energy (NRE)	MJ/ha	113179.36 (93.61%)	93310.72(94.70 %)	72616.47 93.45%)

The source wise energy expenditure pattern for the production of cashew under various plant densities are depicted in Figure 4. Among the different plant densities, chemical fertilizer consumed the maximum energy, followed by diesel fuel. As regards to the share of the total energy, expenditure is concerned the energy consumption per unit area was slightly higher for ultra-density plantation (2.5x2.5 m) as compared to other two spacing (i.e., 5x5 and 7.5x7.5 m). The higher energy expenditure in ultra-density and high-density cashew orchards is mainly due to more number of plants per unit area and increased need for resources for the initial establishment. Comparative analyses of the findings obtained in the present study in terms of energy requirements under different plant densities indicated that the overall energy requirement is decreased over the years, for all planting densities and the yield was increased significantly which in turn increases the total output energy. Forms of renewable/non-renewable and direct/indirect energy sources used in cashew production are also studied for different plant densities and presented in Figure 5. The outcomes indicated that the contribution of direct input energy for different plant densities varied from 21.55 to 25.60% compared to 74.40 to 78.45% for indirect energy sources. Also, non-renewable and renewable energy sources contributed to 93.45 to 94.70% and 3.55 to 6.39% of the overall energy intake, respectively. It is evident that the amount of non-renewable and indirect input energy usage in cashew production is very much high. Energy analysis showed that cashew production is relatively energy efficient in coastal India and is heavily reliant on non-renewable energy and indirect energy sources.

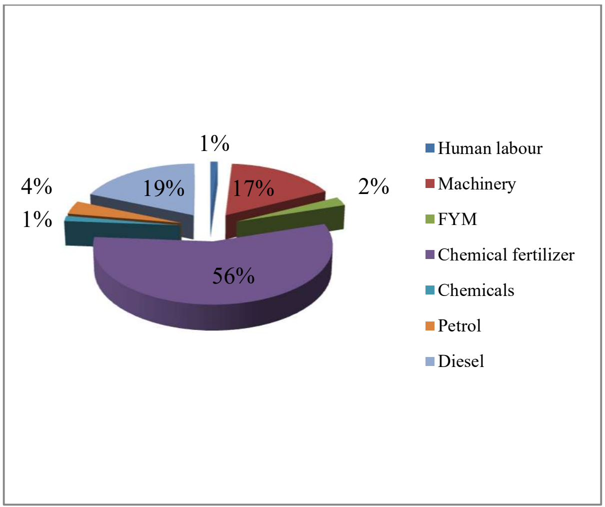

Figure 3: Percentages of total energy input for cashew production (7.5 x 7.5 m spacing)

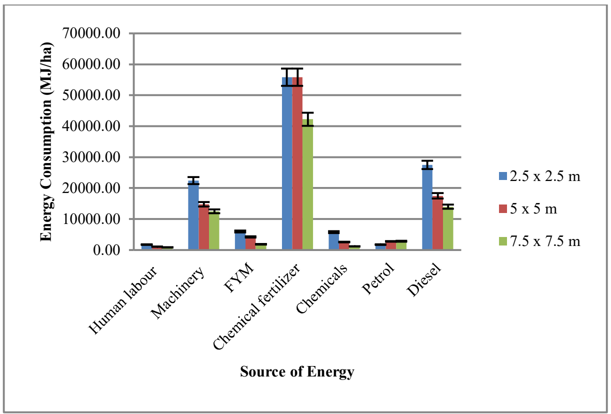

Figure 4: Source wise energy consumption pattern for cashew production under different plant densities.

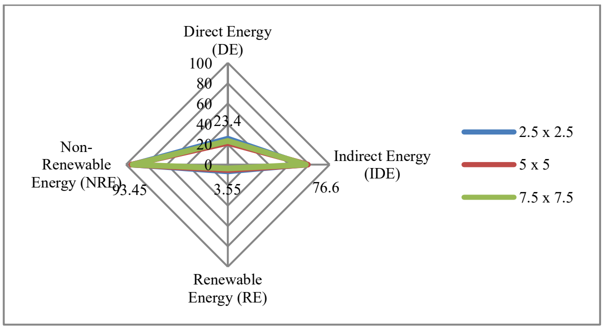

Figure 5: Distribution pattern of total energy input (MJ/ha) in the form of direct energy (DE), indirect energy (IDE), renewable (RE) and non-renewable (NRE) for Cashew cultivation.

The expenditure analysis suggested that the overall energy consumption involved in the current production of cashew in the study area is primarily due to the increased usage of commercial energy sources. These results are in accordance with the energy sources distribution in other fruit crops production *viz*., almond (Beigi *et al*., 2016), pear (Tabatabaie *et al*., 2013), strawberry (Banaeian *et al*., 2011), apple (Rafiee *et al*., 2010) and prune (Tabatabaie *et al*., 2013).

Conclusion

The rate of energy expenditure for input and output energies in cashew production were investigated in this study under different plant densities in coastal India. In this perspective, a set of four energy indices*viz*., energy use efficiency, specific energy, energy productivity and net energy in conjunction with various energy forms, i.e. non-renewable/renewable and direct/indirect were analysed to identify the process of energy input which causes the greatest impact in the life cycle of cashew production. In conclusion, assessment of the energy flow indicated that cashew production is relatively less energy-efficient and is largely dependent on non-renewable and indirect energy sources. The source wise energy contribution indicated that overall energy expenditure related to the current cashew production in the study region is primarily attributed to the management of nutrients (fertilizers) followed by energy from diesel fuel, machinery, FYM, chemicals, petrol and human energy. In this context, different strategies have been suggested to improve the energy efficiency, including the reasonable use of chemical fertilizers, alternatives to minimise the use of chemical fertilizers, and reducing diesel fuel and agricultural machinery to the extent possible as well as the encouragement of the use of renewable energy sources.

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Conflict of interest

The authors declare that they have no conflict of interest.

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