Energy use pattern in sugarcane-based intercropping system in semi-arid region of Karnataka

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ABSTRACT

Efficient energy utilization is essential for improving agricultural productivity and sustainability, particularly in energy-intensive crops such as sugarcane. A field experiment was conducted to evaluate the energy use pattern and efficiency of sugarcane-based intercropping systems under semi-arid conditions of Karnataka. The study included different intercropping combinations with plant cane and ratoon cane and energy inputs and outputs were quantified using standard energy equivalents. Total energy input in plant cane ranged from 34,678 to 46,943 MJ per ha, while energy output ranged from 76,929 to 163,793 MJ per ha across different intercropping systems. Among the treatments, sugarcane intercropped with soybean at 1.2 m spacing recorded the highest energy efficiency (3.82) and net energy (120,889 MJ/ha), mainly due to higher energy contribution from soybean yield. In ratoon cane, total energy input varied from 29,934 to 34,604 MJ per ha and energy output ranged from 19,971 to 89,902 MJ per ha. The highest energy efficiency (2.61) and net energy (55,448 MJ/ha) were recorded in sugarcane intercropped with green pea followed by watermelon. Chemical fertilizers accounted for the highest share of total energy input, followed by seed material and irrigation. Wider row spacing resulted in reduced energy efficiency due to lower crop productivity. The results indicated that sugarcane-based intercropping, particularly with soybean and green pea, improves energy productivity and overall system efficiency compared to sole sugarcane. Therefore, sugarcane-based intercropping systems offer a viable strategy for enhancing energy efficiency and sustainability in semi-arid regions.

Keywords: Sugarcane; Intercropping; Energy efficiency; Energy productivity; Energy use pattern

INTRODUCTION

Agriculture is the process of converting solar energy into food for humans and feed for animals through photosynthesis. In primitive agriculture, farmers simply scattered seeds and harvested whatever grew, using very little energy. In contrast, modern agriculture requires energy at every stage, including operating machinery, irrigation, cultivation and harvesting. Additional energy is also needed after harvest for processing, storage and transportation. Moreover, the production and use of fertilizers, pesticides, insecticides and herbicides represent important indirect energy inputs in agricultural systems. Developed countries have benefited greatly from increased energy use in agriculture, improving productivity and food security. However, many developing countries still depend on human and animal labour due to limited access to mechanical and electrical energy. This lack of modern energy inputs restricts their ability to increase agricultural production and efficiency (https://www.fao.org/4/x8054e/x8054e05.htm).

Sugarcane, a C4 plant, has higher photosynthetic efficiency and captures more solar energy than many other crops. It has been recognized as a potential energy crop for producing liquid fuels and chemicals (Austin et al 1978). In India, sugarcane cultivation requires large amounts of fossil energy and irrigation water. Efficient energy use is essential for sustainable agriculture, as it reduces costs, conserves fossil fuels and lowers pollution (Uhlin 1998). Sugarcane both consumes and produces energy, making it important for a sustainable energy future. Due to its bulky nature and limited mechanization in developing countries, it requires more energy than many other crops, especially for planting, intercultural operations and harvesting. Despite this, sugarcane remains a promising green energy crop for biofuel and ethanol production (Modi and Singh 2023). Iran studies showed that sugarcane farming requires high energy inputs. Karimi et al (2008) reported total energy use of 148.02 GJ per ha and energy output of 112.22 GJ per ha, with an output-input ratio of 0.76. Irrigation was the largest energy consumer (43%), followed by electricity, fertilizers, fuel and machinery. Similarly, Kumar et al (2018) found that in Madhya Pradesh, electricity was the major commercial energy source (75191.32 MJ/ha), while human labour was the main non-commercial energy source (5819.21 MJ/ha).

Shahamat et al (2013) in a study on sugarcane production in Khuzestan province, Iran, found that sugarcane farming required very high energy input (78094.03 MJ/ha), mainly from electricity (33.2%) and irrigation water (25.1%), followed by fertilizers and machinery. Although the crop produced more energy than it consumed, the benefit-cost ratio was only 0.71, indicating that sugarcane cultivation was not economically profitable. The study showed that sugarcane farming in the region was energy-intensive and costly, with heavy dependence on electricity and irrigation.

According to Modi and Singh (2023), India uses the highest energy input in sugarcane production (153,160.5 MJ/ha), while Brazil uses the lowest (22,861.5 MJ/ha). However, both countries produce high energy output, with Brazil showing a much higher net energy gain and the best energy efficiency ratio (17.43), compared to India (2.44), Pakistan (4.35) and Iran (3.64). The study suggested that sugarcane can be a sustainable crop globally, but improving irrigation efficiency is important to reduce energy use. It also recommended using cane node and transplanting methods to lower seed-related energy inputs and improve overall efficiency. Energy use and agricultural productivity are closely linked. Studying energy flow helps understand the efficiency and technology level of crop production systems. Direct energy comes from sources like human labour, animals, tractors and electric motors, while indirect energy includes seeds, manures, fertilizers, insecticides and growth regulators. Factors such as cropping pattern, soil type, fertilizer use, plant protection and yield influence energy efficiency, productivity and overall energy balance in agriculture (Mandal et al 2005).

MATERIAL and METHODS

Both renewable and non-renewable energy sources were included in the energy inputs. Non-renewable energy included chemical fertilizers (NPK), tractors, diesel, electricity, lubricants, machinery and agrochemicals, while renewable energy included manual labour, animal or bullock labour, seed and manure. Both grain and byproduct yields were included in the total physical production. Economic and byproduct yields were used to calculate the output energy, while different inputs and management practices used during crop cultivation were used to calculate the input energy.

These factors were considered while evaluating the efficiency of the system. Energy was calculated for each input used and each output obtained. A system was considered efficient when it produced higher output energy with lower input energy. Standard energy equivalents for different inputs were used for energy analysis as suggested by Singh et al (1997) and Binning et al (1983). The energy equivalents of different inputs and outputs used in the present study are presented in Table 1. The different indices used for energy analysis in the present study are given below.

Energy efficiency (EE): Mega Joules were used to calculate and express the cultural energy used as inputs and the energy produced as products. EE was calculated by considering the input and output energy for each treatment (Dazhong and Pimental 1984):

$$EE = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

Specific energy (SE): The specific energy of the treatment was computed as the amount of energy required to create one kilogram of main product and expressed as MJ per kg:

$$SE = \frac{\text{Energy input (MJ/ha)}}{\text{Grain yield (kg/ha)}}$$

Net energy (NE): The net energy was estimated by subtracting the energy input from the energy output of a specific treatment or activity:

$$NE = \text{Energy output (MJ/ha)} - \text{Energy input (MJ/ha)}$$

Table 1. Energy equivalents for different inputs and outputs in sugarcane production

Component	Unit	Energy equivalent (MJ/unit)	Reference
Input			
Human labour (adult man)	Man hour	1.96 MJ	Gopalan et al (1989)
Human labour (woman)	Woman hour	1.57 MJ	
Animal	Bullock pair/day	64.56 MJ	
Diesel	l	56.31 MJ (includes cost of lubricants)	
Petrol	l	48.23 MJ (includes cost of lubricants)	
Electricity	KWh	11.93 MJ	
Machinery			
Electric motor	h	64.8 MJ	
Farm machinery including self-propelled machines	h	62.7 MJ	
Chemical fertilizers			
Nitrogen	kg	60.60 MJ	
Phosphorus (P_2O_5)	kg	11.10 MJ	
Potassium (K_2O)	kg	6.70 MJ	
Farmyard manure (FYM)	kg	0.3	
Chemicals (superior)	kg	120	
Water	M^3	0.63	Gundogmus (2006)
Seed cuttings and stalks (sugarcane)	kg	1.2	Ricaud (1980)
Output			
Seed cuttings and stalks (sugarcane)	kg	1.2	
Soybean	kg	18.6 MJ (446 kcal/100 g)	Anon (2016e)
Green pea (dry)	100 g	352 kcal (1.48 MJ)	Anon (2016f)
	kg	14.8 MJ	
Green pea (tender)	100 g	81 kcal	Anon (2016d)
	kg	3.38 MJ	
Onion bulb	100 g	40 kcal (0.16736 MJ)	Anon (2016c)
	kg	1.67 MJ	
Watermelon fruit	100 g	30 kcal (0.12552 MJ)	Anon (2016b)
	kg	1.26 MJ	
Cucumber fruit	100 g	15 kcal (0.06276 MJ)	Anon (2016a)
	kg	0.63	
Byproduct (Stem/stover)	kg	12.5	Gopalan et al (1989)
Watermelon seeds	kg	23.473	Gravalos et al (2016)
Cucumber seeds	100 g	446 cal	Anon (2016a)
	kg	0.018 MJ	
Onion seeds	kg	0.016 MJ	Anon (2016c)

Energy productivity (EP): Energy productivity is the amount of physical output obtained for each unit of input and was expressed in kg per MJ:

$$EP = \frac{\text{Output (grain + byproduct) (kg/ha)}}{\text{Energy input (MJ/ha)}}$$

Energy intensity (EI): Energy intensity as MJ per ha in physical terms or MJ per rupee in economic terms, is the ratio of energy output to total physical output or cultivation expenses.

In physical terms (MJ/ha):

$$EP = \frac{\text{Energy output (MJ/ha)}}{\text{Output (grain + byproduct) (kg/ha)}}$$

In economic terms (MJ/ha)%

$$EI = \frac{\text{Energy output (MJ/ha)}}{\text{Cost of cultivation (Rs)}}$$

RESULTS and DISCUSSION

Among the different inputs used in sugarcane-based intercropping systems, highest energy was utilized for chemical fertilizers followed by sugarcane seeding material and irrigation (Tables 2, 4).

Energy use and energy production (plant cane)

Among different intercropping systems, energy input was higher in sugarcane at 1.2 m + drill sown onion (46,943 MJ/ha) and lower in sole sugarcane at 3.6 m (34,678 MJ/ha). Energy output was higher in sugarcane at 1.2 m + soybean intercropping system (163,793 MJ/ha) and lower in sole sugarcane at 3.6 m row spacing (76,929 MJ/ha). Energy efficiency and net energy were higher in sugarcane at 1.2 m + soybean (3.82 and 120,889 MJ/ha) compared to other intercropping systems.

Table 2 shows the energy requirements to grow plant cane in Karnataka. Total energy used to grow one hectare of sugarcane ranged from 34,678 to 46,943 MJ per ha among different treatments. Indirect energy included energy embodied in sugarcane stem cuttings, fertilizers, chemicals and machinery while direct energy covered human labour and diesel used in the sugarcane production.

Energy outputs among different cropping systems ranged from 76,929 MJ per ha to 163,793 MJ per ha. Data in Table 4 show that in the studied region, the energy efficiency (3.59) and net energy (118,145 MJ/ha) were the highest in sugarcane at 1.2 m + soybean. This might be due to higher energy content in soybean output ie grains (18.6 MJ/kg) which was higher than tender green pea (3.38 MJ/kg) and drill sown onion bulb (1.67 MJ/kg).

Energy use and energy production (ratoon cane)

Among different intercropping systems, energy input was higher in sugarcane at 1.2 m + green pea followed by cucumber (34,604 MJ/ha) and lower in sole sugarcane at 3.6 m (29,934 MJ/ha) (Table 3). However, the energy output was higher in sugarcane at 1.2 m + green pea followed by watermelon in ratoon (89,902 MJ/ha) and lower in sugarcane at 3.6 m + soybean followed by cucumber in ratoon (19,971 MJ/ha) (Table 5). Energy efficiency and net energy in ratoon sugarcane were higher in sugarcane at 1.2 m + green pea followed by watermelon (2.61 and 55,448) compared to other intercropping systems.

Table 3 shows the energy requirements to grow ratoon cane in Karnataka. Total energy used to grow one ha of ratoon cane ranged from 29,934 to 34,604 MJ per ha among different treatments. Indirect energy included energy embodied in sugarcane settlings, fertilizers, chemicals, machinery while direct energy covered human labour and diesel used in the sugarcane production.

Table 5 shows that in the studied region, the energy efficiency (2.61) and net energy (55,448 MJ/ha) were the highest in sugarcane at 1.2 m + green pea followed by watermelon in ratoon. This may be due to higher yield of sugarcane in this treatment compared to other intercropping systems. The net energy values were negative in sugarcane at 3.6 m spacing. This could be because of low yield of sugarcane at 3.6 m spacing. It can also be noticed that the energy efficiency decreased with increase in row spacing due to lower yields of sugarcane at 2.4 m and 3.6 m paired row spacings compared to 1.2 m spacing.

CONCLUSION

The present study demonstrated that sugarcane-based intercropping systems significantly influence energy use efficiency and overall system productivity under semi-arid conditions of Karnataka. Among the different energy inputs, chemical fertilizers contributed the largest share, followed by seed material and irrigation, highlighting the importance of efficient nutrient and water management in reducing total energy consumption.

Intercropping sugarcane with soybean in plant cane and green pea followed by watermelon in ratoon cane recorded the highest energy efficiency and net energy compared to other intercropping systems and sole sugarcane. This improvement was mainly due to higher total biomass production and additional energy output from intercrops. In contrast, wider row spacing resulted in lower energy efficiency and, in some cases, negative net energy due to reduced crop yield and inefficient utilization of inputs.

Overall, sugarcane-based intercropping systems proved to be more energy-efficient and productive than sole sugarcane cultivation. These systems enhance energy productivity, improve resource utilization and contribute to sustainable agricultural

Table 2. Energy input (MJ/ha) in different treatments in plant cane

Component	Treatment											
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
Land preparation												
Cultivator	1,471.7	1,471.7	1,471.7	1,471.7	1,471.7	1,471.7	1,471.7	1,471.7	1,471.7	1,471.7	1,471.7	1,471.7
Rooter and line marking	889.4	889.4	889.4	889.4	889.4	889.4	889.4	889.4	889.4	889.4	889.4	889.4
Planting of sugarcane setts	62.8	62.8	62.8	62.8	62.8	62.8	62.8	62.8	62.8	62.8	62.8	62.8
Sowing of intercrops												
Soybean	62.8	-	-	-	62.8	-	-	-	62.8	-	-	-
Green pea	-	62.8	-	-	-	62.8	-	-	-	62.8	-	-
Onion	-	-	62.8	-	-	-	62.8	-	-	-	62.8	-
Sugarcane setts (variety CO86032)	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	6,000	6,000	6,000	6,000
Sugarcane settlings for gap filling	1,800	-	-	-	1,800	-	-	-	1,800	-	-	-
Labour for gap filling of sugarcane settlings	13.3	-	-	-	13.3	-	-	-	13.3	-	-	-
Intercrop seeds												
Soybean (variety JS9305)	1,162.5	-	-	-	1,162.5	-	-	-	1,162.5	-	-	-
Green pea (variety AP3)	-	444	-	-	-	444	-	-	-	444	-	-
Onion (variety N-53)	-	-	1.6	-	-	-	1.6	-	-	-	1.6	-

Table 2. Contd…..

Component	Treatment											
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
Fertilizers and inter-cultivation												
Fertilizers (for sugarcane)	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5
Fertilizers (for intercrop)	3,479.5	2,405.0	8,967.5	-	3,479.5	2,405.0	8,967.5	-	3479.5	2,405.0	8,967.5	-
Hand weeding	20.3	40.6	40.6	40.6	20.3	40.6	40.6	40.6	20.3	40.6	40.6	40.6
Inter-cultivation (by power tiller)	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5
Drip irrigation	7,499.4	7,499.4	7,499.4	7,499.4	7,499.4	7,499.4	7,499.4	7,499.4	7,499.4	7,499.4	7,499.4	7,499.4
Plant protection chemicals												
Chloropyriphos	180	180	180	180	180	180	180	180	180	180	180	180
Mancozeb 75 WP	240	-	-	-	240	-	-	-	240	-	-	-
Atrazine	300	300	300	300	300	300	300	300	300	300	300	300
Dimethoate 30 EC	-	-	79.2	-	-	-	79.2	-	-	-	79.2	
Labour for pesticide application	-	-	-	-	-	-	-	-	-	-	-	-
Harvesting	-	-	-	-	-	-	-	-	-	-	-	-
Labour for harvesting of intercrops												
Soybean	48.8	-	-	-	48.8	-	-	-	48.8	-	-	-
Green pea	-	15.6	-	-	-	15.6	-	-	-	15.6	-	-
Onion	-	-	62.4	-	-	-	62.4	-	-	-	62.4	-
Labour for harvesting of sugarcane	214.2	223.3	216.4	218.1	173.9	181.7	160.8	184.3	110.0	162.2	145.1	125.7
Energy input (MJ/ha)	45,648	40,704	46,943	37,771	45,608	40,662	46,887	37,737	42,544	37,642	43,871	34,678

T_1: Sugarcane at 1.2 m + soybean, T_2: Sugarcane at 1.2 m + green pea, T_3: Sugarcane at 1.2 m + drill sown onion, T_4: Sole sugarcane at 1.2 m, T_5: Sugarcane at 2.4 m + soybean, T_6: Sugarcane at 2.4 m + green pea, T_7: Sugarcane at 2.4 m + drill sown onion, T_8: Sole sugarcane at 2.4 m, T_9: Sugarcane at 3.6 m + soybean, T_{10}: Sugarcane at 3.6 m + green pea, T_{11}: Sugarcane at 3.6 m + drill sown onion, T_{12}: Sole sugarcane at 3.6 m

Table 3. Energy input (MJ/ha) in different treatments in ratoon cane

Component	Treatment										
	T_{1a}	T_{1b}	T_{2a}	T_{2b}	T_{3a}	T_{3b}	T_{4}	T_{5a}	T_{5b}	T_{6a}	T_{6b}
Ratoon crop management practices											
Trash removal (ratoon)	40.8	40.8	40.8	40.8	40.8	40.8	40.8	40.8	40.8	40.8	40.8
Stubble shaving	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8
Inter-cultivation (by power tiller)	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5
Sugarcane settlings for gap filling	2894.4	2894.4	2894.4	2894.4	2894.4	2894.4	2894.4	2894.4	2894.4	2894.4	2894.4
Labour for gap filling	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7
Sowing of intercrops											
Cucumber	15.7	-	15.7	-	15.7	-	-	15.7	-	15.7	-
Watermelon	-	15.7	-	15.7	-	15.7	-	-	15.7	-	15.7
Seeds											
Cucumber (variety Belgaum Local)	0.05	-	0.05	-	0.05	-	-	0.05	-	0.05	-
Watermelon (hybrid Madhubala)	-	82.16	-	82.16	-	82.16	-	-	82.16	-	82.16
Fertilizers (sugarcane)	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5
Fertilizers (intercrop)	4526	4312	4526	4312	4526	4312		4526	4312	4526	4312
Hand weeding	40.8	40.8	40.8	40.8	40.8	40.8	40.8	40.8	40.8	40.8	40.8
Intercultivation (by power tiller) at 120 DAP	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5
Drip irrigation	7,499	7,499	7,499	7,499	7,499	7,499	7,499	7,499	7,499	7,499	7,499
Plant protection chemicals											
Lacenta	60	60	60	60	60	60	60	60	60	60	60
Dantotsu (Clothianidin 50 WDG)	60	60	60	60	60	60	60	60	60	60	60
Atrazine	300	300	300	300	300	300	300	300	300	300	300
Labour for pesticide application	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
Harvesting											
Labour for harvesting of intercrops											
Cucumber	28.3	-	28.3	-	28.3	-	-	28.3	-	28.3	-
Watermelon		12.56		12.56		12.56			12.56		12.56
Labour for harvesting of sugarcane	120.8	116.7	142.9	140.3	109.3	113.4	117.3	100.6	95.8	97.3	89.9
Energy input (MJ/ha)	34,582	34,431	34,604	34,454	34,571	34,427	30,009	34,562	34,410	34,559	34,404

T_{1a}: Sugarcane at 1.2 m + soybean *fb* Cucumber in ratoon, T_{1b}: Sugarcane at 1.2 m + soybean *fb* watermelon in ratoon, T_{2a}: Sugarcane at 1.2 m + green, pea *fb* cucumber in ratoon, T_{2b}: Sugarcane at 1.2 m + green pea *fb* watermelon in ratoon, T_{3a}: Sugarcane at 1.2 m + drill sown onion *fb* cucumber in ratoon, T_{3b}: Sugarcane at 1.2 m + drill sown onion *fb* watermelon in ratoon, T_{4}: Sole sugarcane at 1.2 m *fb* sole sugarcane at 1.2 m, T_{5a}: Sugarcane at 2.4 m + soybean *fb* cucumber in ratoon, T_{5b}: Sugarcane at 2.4 m + soybean *fb* watermelon in ratoon, T_{6a}: Sugarcane at 2.4 m + green pea *fb* cucumber in ratoon, T_{6b}: Sugarcane at 2.4 m + green pea *fb* watermelon in ratoon

Table 3. Contd…..

Component	Treatment									
	T_{7a}	T_{7b}	T_{8}	T_{9a}	T_{9b}	T_{10a}	T_{10b}	T_{11a}	T_{11b}	T_{12}
Ratoon crop management practices										
Trash removal (ratoon)	40.82	40.82	40.82	40.82	40.82	40.82	40.82	40.82	40.82	40.82
Stubble shaving	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8
Inter-cultivation (by power tiller)	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5
Sugarcane settings for gap filling	2,894.4	2,894.4	2,894.4	2,894.4	2,894.4	2,894.4	2,894.4	2,894.4	2,894.4	2,894.4
Labour for gap filling	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7
Sowing of intercrops										
Cucumber	15.7	-	-	15.7		15.7		15.7	-	-
Watermelon	-	15.7	-	-	15.7	-	15.7	-	15.7	-
Seeds										
Cucumber (variety Belgaum Local)	0.045	-	-	0.045	-	0.045	-	0.045	-	-
Watermelon (hybrid Madhubala)		82.16			82.16		82.16		82.16	
Fertilizers (sugarcane)	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5	17,255.5
Fertilizers (intercrop)	4526	4312		4526	4312	4526	4312	4526	4312	
Hand weeding	40.8	40.8	40.8	40.8	40.8	40.8	40.8	40.8	40.8	40.8
Inter-cultivation (by power tiller) at 120 DAP	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5	853.5
Drip irrigation	7,499.4	7,499.4	7,499.4	7,499.4	7,499.4	7,499.4	7,499.4	7,499.4	7,499.4	7,499.4
Plant protection chemicals										
Lacenta	60	60	60	60	60	60	60	60	60	60
Dantotsu (Clothianidin 50 WDG)	60	60	60	60	60	60	60	60	60	60
Atrazine	300	300	300	300	300	300	300	300	300	300
Labour for pesticide application	5.88	5.88	5.88	5.88	5.88	5.88	5.88	5.88	5.88	5.88
Harvesting										
Labour for harvesting of intercrops										
Cucumber	28.26	-	-	28.26	-	28.26	-	28.26	-	-
Watermelon		12.56			12.56		12.56		12.56	
Labour for harvesting of sugarcane	109.32	115.11	79.73	56.62	53.32	59.07	53.46	57.56	50.39	42.64
Energy input (MJ/ha)	34,571	34,429	29,971	34,518	34,367	34,520	34,367	34,519	34,364	29,934

T_{7a}: Sugarcane at 2.4 m + drill sown onion *fb* cucumber in ratoon, T_{7b}: Sugarcane at 2.4 m + drill sown onion *fb* watermelon in ratoon, T_{8}: Sole sugarcane at 2.4 m fb sole sugarcane at 2.4 m, T_{9a}: Sugarcane at 3.6 m + soybean *fb* cucumber in ratoon, T_{9b}: Sugarcane at 3.6 m + soybean *fb* watermelon in ratoon, T_{10a}: Sugarcane at 3.6 m + green pea*fb* cucumber in ratoon, T_{10b}- Sugarcane at 3.6 m + green pea*fb* watermelon in ratoon, T_{11a}: Sugarcane at 3.6 m + drill sown onion *fb* cucumber in ratoon, T_{11b}: Sugarcane at 3.6 m + drill sown onion *fb* watermelon in ratoon, T_{12}: Sugarcane at 3.6 m *fb* sole sugarcane at 3.6 m

Table 4. Energy indices in sugarcane-based intercropping systems as influenced by row spacing in plant cane

Treatment (planting pattern)	Mix proportion (%)	Energy input (MJ/ha)	Total energy output (cane + intercrop) (MJ/ha)	Energy efficiency	Net energy (MJ/ha)
T_1: Sugarcane at 1.2 m + soybean (1:4)	100: 84	45,648	163,793	3.59	1,18,145
T_2: Sugarcane at 1.2 m + green pea (1:4)	100: 84	40,704	139,892	3.44	99,188
T_3: Sugarcane at 1.2 m + drill sown onion (1:4)	100: 84	46,943	140,399	2.99	93,456
T_4: Sole sugarcane at 1.2 m		37,771	133,525	3.54	95,754
T_5: Sugarcane at 2.4 m + soybean (2:7)	100: 75	45,608	137,288	3.01	91,680
T_6: Sugarcane at 2.4 m + green pea (2:7)	100: 75	40,662	113,751	2.80	73,089
T_7: Sugarcane at 2.4 m + drill sown onion (2:7)	100: 75	46,887	105,851	2.26	58,964
T_8: Sole sugarcane at 2.4 m		37,737	112,808	2.99	75,071
T_9: Sugarcane at 3.6 m + soybean (2:10)	67: 79	42,544	98,803	2.32	56,259
T_{10}Sugarcane at 3.6 m + green pea (2:10)	67: 79	37,642	101,904	2.71	64,261
T_{11}: Sugarcane at 3.6 m + drill sown onion (2:10)	67: 79	43,871	96,420	2.20	52,549
T_{12}: Sole sugarcane at 3.6 m		34,678	76,929	2.22	42,250

production in semi-arid regions. Therefore, adoption of suitable intercropping combinations such as sugarcane + soybean and sugarcane + green pea can be recommended to improve energy efficiency, profitability and sustainability of sugarcane cultivation.

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Table 5. Energy indices as affected by ratoon sugarcane-based intercropping systems

Treatment	Energy input (MJ/ha)	Total energy output (cane + intercrop) (MJ/ha)	Energy efficiency	Net energy (MJ/ha)
T_{1a}: Sugarcane at 1.2 m + soybean (1:4) *fb* cucumber (1:1) in ratoon	34,582	70,728	2.05	36,146
T_{1b}: Sugarcane at 1.2 m + soybean (1:4) *fb* watermelon (2:1) in ratoon	34,431	84,169	2.44	49,739
T_{2a}: Sugarcane at 1.2 m + green pea (1:4) *fb* cucumber (1:1) in ratoon	34,604	87,659	2.53	53,055
T_{2b}: Sugarcane at 1.2 m + green pea (1:4) *fb* watermelon (2:1) in ratoon	34,454	89,902	2.61	55,448
T_{3a}: Sugarcane at 1.2 m + drill sown onion (1:4) *fb* cucumber (1:1) in ratoon	34,571	78,238	2.26	43,667
T_{3b}: Sugarcane at 1.2 m + drill sown onion (1:4) *fb* + watermelon (2:1) in ratoon	34,427	73,078	2.12	38,651
T_4: Sole sugarcane at 1.2 m *fb* sole sugarcane at 1.2 m	30,009	77,325	2.58	47,316
T_{5a}: Sugarcane at 2.4 m + soybean (2:7) *fb* cucumber (2:2) in ratoon	34,562	59,034	1.71	24,472
T_{5b}: Sugarcane at 2.4 m + soybean (2:7) *fb* watermelon (2:1) in ratoon	34,410	59,272	1.72	24,863
T_{6a}: Sugarcane at 2.4 m + green pea (2:7) *fb* cucumber (2:2) in ratoon	34,559	48,741	1.41	14,182
T_{6b}: Sugarcane at 2.4 m + green pea (2:7) *fb* watermelon (2:1) in ratoon	34,404	53,935	1.57	19,531
T_{7a}: Sugarcane at 2.4 m + drill sown onion (2:7) *fb* cucumber (2:2) in ratoon	34,571	57,826	1.67	23,255
T_{7b}: Sugarcane at 2.4 m + drill sown onion (2:7) *fb* watermelon (2:1) in ratoon	34,429	50,891	1.48	16,462
T_8: Sole sugarcane at 2.4 m *fb* sole sugarcane at 2.4 m	29,971	44,382	1.48	14,411
T_{9a}: Sugarcane at 3.6 m + soybean (2:10) *fb* cucumber (2:3) in ratoon	34,518	19,971	0.58	–14,547
T_{9b}: Sugarcane at 3.6 m + soybean (2:10) *fb* watermelon (2:2) in ratoon	34,367	26,928	0.78	–7,440
T_{10a}: Sugarcane at 3.6 m + green pea (210) *fb* cucumber (2:3) in ratoon	34,520	21,936	0.64	–12,585
T_{10b}: Sugarcane at 3.6 m + green pea (2:10) *fb* watermelon (2:2) in ratoon	34,367	24,835	0.72	–9,532
T_{11a}: Sugarcane at 3.6 m + drill sown onion (2:10) *fb* cucumber (2:3) in ratoon	34,519	30,151	0.87	–4,368
T_{11b}: Sugarcane at 3.6 m + drill sown onion (2:10) *fb* watermelon (2:2) in ratoon	34,364	29,435	0.86	–4,929
T_{12}: Sugarcane at 3.6 m *fb* sole sugarcane at 3.6 m	29,934	29,852	1.00	–82

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