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Energy Auditing of Cape Gooseberry (*Physalis peruviana* L.) Production with Agronomic Manipulations in Sodic Soils of Indo-gangetic Plains

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Authors' contributions

This work was carried out in collaboration between both authors. Authors AA and BPS Conceptualization, methodology, formal analysis, investigation, resources, data curation. Author AA writing-original draft preparation. Authors AA and BPS writing-review and editing, visualization, supervision. *Both authors read and approved the final manuscript.*

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ABSTRACT

This study investigated the energy input-output relationship in biomass production of cape gooseberry (*Physalis peruviana* L.) grown in Sodic soils of Indo-Gangetic plains with agronomic manipulations of plant spacing (90 x 75 cm, 75 x 75 cm, 75 x 75 cm) and NPK fertilizers (0, 60:40:40, 80:60:60, 100:80:80 $N:P_2O5:K_2O$ kg ha^{-1}). Results indicated that total input energy requirements in various treatments ranged from 16784.72 MJ ha^{-1} in 90 x 75 cm spacing without NPK fertilizers to 24395.04 MJ ha^{-1} in case of 75 x 60 cm spacing with NPK at 100:80:80 kg ha^{-1}. Irrespective of agronomic manipulations, share of non-renewable energy in total input energy was very high (64.56%) and the percentage proportions of direct and indirect energies in the total input energy were 75.56 and 24.13%, respectively. Among various inputs, diesel accounted for the greatest proportion (40.44%) of total input energy, followed by water (32%), fertilizers (19.28%) and these three inputs constituted 92.08% of total input energy. Crop raised at 75 x 60 cm spacing with

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NPK at 100:80:80 kg ha^{-1} resulted the highest output energy (80863 MJ ha^{-1}), net energy return (56529.91 MJ ha^{-1}) and energy use efficiency (3.22); however, the results obtained at 75 x 60 cm spacing with NPK at 100:80:80 kg ha^{-1} were comparable. The best energy productivity (0.43) was achieved with 75 x 75 cm spacing and 100:80:80 kg NPK ha^{-1}.

Keywords: Agronomic manipulations; energy productivity; energy use efficiency; NPK fertilizers; Physalis peruviana L; spacing.

1. INTRODUCTION

Soil salinity is one of the most critical factors limiting agricultural productivity by affecting physiological aspects of plant growth and development [1-3]. Around 1.12 billion hectares of arable land worldwide are affected by various types of soil salinity, with 6.73 million hectares of salt-affected soils scattered across India [4-6]. Soil salinity affects around 2.1% of India's geographical area, of which 2.96 million ha are saline and the other 3.77 million ha are sodic [5,6]. It has been postulated that every year nearly 10% additional area is getting salinized and by 2050, around 50% of the arable land will be salt-affected [4]. The Indo-Gangetic plain is among the most extensive land tract of the world and covers several states of the northern, central and eastern parts of India. It stretches westwards from the combined delta of the Bramhaputra and Ganges river valleys to the Indus river valley and occupies about 43.7 m ha [7]. This plain accounts for about 2.35 million ha of the salt-affected soils of India, of which 0.56 million ha are saline and about 1.78 million ha are sodic [8]. Appropriate technical interventions such as reduced amendment use, additional nutrition and drip irrigation, the exploration of salt-tolerant species of economic importance for viable farming are needed in salt-affected soils of indo-Gangetic plain. Among cultivated species, major fruit crops are more sensitive to salinity than common annual crop species; however, hardy fruit species such as *Grewia asiatica*, *Phoenix dactylifera*, *Manilkara zapota*, *Psidium guajava*, *Syzygium cuminii*, *Ziziphus mauritiana*, *Emblica officinalis*, *Carissa carandas*, *Punica granatum*, *Aegle marmelos* and few more have tremendous commercial potential in salt-affected soils [9-11]. All of these fruit trees are perennial with a longer gestation period before harvesting economic yield resulting in delayed viable income to the growers in such vulnerable areas.

Cape gooseberry *(Physalis peruviana* L.) is a herbaceous semi-shrub of the nightshade family (Solanaceae) that bears numerous small fruits (berries) enclosed in an inflated papery calyx cavity. It is native to Aden regions of South America [12-14]. This crop was introduced to South Africa by Spanish explorers during the 19th century, from where it spread to various tropical countries [14]. Several other names are used for this crop such as golden berry, giant groundcherry, African ground cherry, Aztec berry, Peruvian cherry, Uchuva, Uvilla, Poha and Poha berry. In India it is commonly known as Rasbhai, Makoi, or Tepari [15].

Cape gooseberry has been recognized as a functional food due to its high quality, and it has attracted the interest of functional food markets. The attractive golden-colored fruits of cape gooseberry are eaten fresh and used in fruit salads and drinks. Fruits are also preserved and dehydrated for use in baking items. Fruits are used to make high-quality jam, which is why it is also known as the "Jam Fruit of India" [12]. Cape gooseberry fruits and other plant parts (leaves, body, seed and pomace) are valuable sources of secondary metabolites for phyto-pharmacy, novel medicine and cosmetics [16]. The fruits contain high amounts of health-promoting compounds [17-20], micronutrient, phosphorous and calcium [15], carotenoids, flavonoids [21-22] and have antioxidants [15,17,22]. Cape gooseberry being explored for its potential role as anticancer, anti-mycobacterial, antipyretic, immune-modulatory properties [23,24], anti-inflammatory, antioxidant and anti-hepatotoxic activities [15,17,18,23] and treating various ailments such as diabetes, asthma, malaria, dermatitis, hepatitis and ulcers [24-26].

Currently, cape gooseberry plants are widely distributed in temperate and tropical regions around the world [14,27]. They have wide adaptability of soil and climatic conditions [12] and are commercially cultivated in Peru, Brazil, Chile, Ecuador, Colombia, South Africa, Kenya, Egypt, Zimbabwe, New Zealand, Australia, India, China, Hawaii and Caribbean countries [27,28]. In Colombia, Cape gooseberry is widely grown in salt-affected soils, protecting itself from salinity stress by increasing leaf antioxidant activity [29] and has been classified as a moderately salt-tolerant crop [30]. Cape gooseberry is grown in pockets of the plains of north India and some areas of southern states. Because of its salt tolerance ability, availability of fresh fruits during the lean season (December to March), wide adaptability, non-perennial occupation of land, rapid growth in nature and high market value, it has a strong potential for commercial production in salt affected soils in India.

Crop productivity in a particular area is impacted by technological (agronomic interventions, managerial decisions and so on), biological (diseases, insects, pests and weeds) and environmental factors (climatic, soil, topography, water, etc.). Planting density and nutrient management are the most important agronomic factors of crop production since these inputs have a stronger impact on plant development and yield. Plant spacing varies depending on the plant type and the environment; thus, appropriate planting density is required for optimum crop growth and development in a specific growing state. Adequate fertilizer management is critical for soil fertility management since it is more responsible for crop performance in a particular setting. Plants require substantial amounts of nitrogen, phosphorus and potassium, as these are insufficiently available in sodic soils for maximum plant growth and development; it is critical to feed these nutrients to the crop in balanced amounts.

Inputs and methods are being intensified in changing technological interventions and modernization of crop production systems to attain enhanced agricultural productivity on constrained cultivable lands. Natural resources, on the other hand, are fast depleting and the amount of pollutants in the environment is significantly increasing [31]. As a result, inputs and methods in modern crop production practises on problem soils must be evaluated in terms of energy to ensure that limited resources are used efficiently for enhanced crop productivity and long-term environmental implications. Evidence suggests that efficient and effective energy use is required for financial savings, fossil resource preservation [32], reduced greenhouse gas emissions from agricultural production systems and energy-related environmental pollution [33,34], improved agricultural production [31,34,35] and ultimately positive contribution to sustainable development [33,36]. Limited study on energy budgeting in agricultural production systems has been conducted in a few countries, with the majority of studies focusing on cereal crops and cropping system research [37-50]. A few studies from India have also been reported, revealing that the energy consumption pattern varied greatly with agro-climatic zones and energy sources with farmers to engage in agricultural business [51-56]. Energy input-output analysis of fruit production systems in India is quite rare, with only a handful in perennial fruit crops. In India, the fruit sector is transitioning from a traditional to a contemporary production system by consuming and producing various forms of energy; consequently, it is critical to research the energy flow in fruit culture and to build optimal energy input relationships.

Until recently, no study on the energy input-output analysis of cape gooseberry production in India or other countries have been reported. With the foregoing in mind, it is crucial to examine the energetics of cape gooseberry growing, since this crop has significant potential for commercialization on a wide scale in salt-affected soils. Hence, the present study sought to investigate the energy requirements and energy input-output relationship of the cape gooseberry (*Physalis peruviana* L.) crop grown on Sodic soils in Northern India under varied agronomic manipulations of plant spacing and NPK fertiliser levels.

2. MATERIALS AND METHODS

2.1 Site Characteristics

A field experiment was set up in a Sodic soil at the Main Experimental Station of the Department of Horticulture, Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Padesh, India (latitude 26°47′ N, longitude 85°12′ E, and elevation 113 meters above mean sea level). The site is located in the Indo-Gangetic plains of India. This location has a sub-humid and sub-tropical climate with mean annual rainfall of 1190 mm, which is mostly received from July to September, but there are also showers in the winter (October-mid February) and summer (April-mid June). Deep ploughing by disc plough, ploughing by cultivator, followed by harrowing and plank to level the field with friable soil, was used to prepare the field for the experiment. After the site had been prepared for transplanting, a soil sample (0 to 30 cm depth) was obtained with an auger and evaluated for physical and chemical parameters using standard protocols [57-61]. The physico-chemical parameters of experimental soil are presented in Table 1.

2.2 Treatments

A total of twelve agronomic manipulations were tried for growing cape gooseberry production, involving three plant spacings (S1 - 75 x 60 cm, S2 - 75 x 75 cm and S3 - 90 x 75 cm) and four NPK levels (F_1 - no NPK fertilizers, F_2 - 60:40:40, F_3 - 80:60:60 kg and F_4 - 100:80:80 kg ha^{-1}; N, P_2O_5 and K_2O, respectively) were formulated for raising cape gooseberry crop. The source of NPK fertilizers used were urea (46% N), single superphosphate (16% P_2O_5), and murate potash (60% K_2O). During the final preparation of the experimental soil, one-third of the nitrogen and the entire amount of phosphorus and potassium were applied according to the treatment plan. The remaining nitrogen was divided into two equal halves and top dressed 45 and 75 days after transplantation.

2.3 Crop Management

Cape gooseberry genotype S-101 (Suttind Seeds Pvt. Ltd, New Delhi) was used in this study. Seedlings were raised in a semi-control polyhouse and four week old seedlings with consistent vigor and size were transplanted in field on July 10, 2004 and July 09, 2005 for two-year experiments. Planting was carried out according to the treatment's specified plant spacing. Other cultural practices, such as irrigation, manual weeding and pesticide application were consistent across all treatments. Each treatment received irrigation totaling 6600 m^3 water ha^{-1} (mean of two years). A diesel-powered air-cooled engine (Kirloskar, India) was utilised to lift groundwater for irrigation.

2.4 Yield Measurements

Ripe fruits were harvested periodically during fruiting season and crop residue was harvested after last picking of fruits manually. The weight of fruits as well as crop residue was measured with a Digital weighing machine (Make: Eagle, India). The cumulative biomass yield (t ha^{-1}) was estimated by adding all the weight fruits and crop residue according to the treatments.

2.5 Estimation of Energy

All the inputs applied and crop outputs (biomass yield) realized in this study were used to evaluate energy budgeting and energy relations, whereas environmental inputs (solar radiation, precipitation, wind, soil nutrients and so on) were not considered in the current study's analysis despite the fact that these environmental inputs represent far higher inputs. Even solar radiation alone is so powerful that including it in the energy analysis would obscure any variability in support energy.

The input-output of cape gooseberry production in terms of energy value were estimated using crop management inputs and crop biomass harvested. A complete inventory of all inputs and outputs (crop biomass) was made to work out the equivalent energy used in crop production and resultant energy outputs. The inputs and crop outputs harvested in this study were converted to common energy units [MJ ha^{-1}] using their energy equivalent coefficients in Table 2 [62-64].

Crop input sources can be divided into two categories: direct and indirect energy sources. The direct energy sources used in this study are those that release energy directly, such as diesel, movers and manual labor; while and the chemical fertilizers, pesticides and machinery are indirect energy sources. Natural energy sources such as radiation rain, and wind, among others, are also direct energy sources; however, these sources were not used by growers and thus were not considered in this study.

Table 1. Soil physico-chemical parameters of the experimental field

Particulars	Value
Bulk density	1.34 g cm^{-3}
Particle density	2.56 g cm^{-3}
Porosity	44.37%
Soil reaction (pH)	8.56
Electrical conductivity	0.42 mmohs cm^{-1}
Organic carbon	0.35%
Available nitrogen	190.44 kg ha^{-1}
Available phosphorus	17.86 kg ha^{-1}
Available potassium	229.34 kg ha^{-1}

Table 2. Energy equivalent of inputs and outputs

Particular	Unit	Energy equivalent (MJ Unit^{-1})
Input		
Human labor		
Male laborer	h	1.96
Female laborer	h	1.57
Chemical fertilizers		
N	kg	60.6
P_2O_5	kg	11.1
K_2O	kg	6.7
Diesel	l	56.31
Farm machinery	kg	62.7
Irrigation water	m^3	1.02
Pesticides	l	120
Seeds	kg	1.0
Tractor	h	13.5
Disc harrow	h	25.08
Cultivator	h	8.36
Sprayer	h	0.17
Pump set (5HP)	h	0.93
Output		
Fruits	kg	1.9
Crop residue	kg	10.0

Based on replenishment and exhaustibility, both direct and indirect energy sources have been classified as renewable and non-renewable. Direct energy sources such as animate, solar, wind and water are non-depleting in nature and can be replenished, making them direct renewable energy sources, while diesel and electricity produce energy directly, these are quickly depleted or exhausted when used. Similarly, indirect energy sources such as biomass and manure can be replenished over time and thus qualify as indirect renewable energy sources, while fertilizer, chemicals and machinery are not replenished; these are classified as non-renewable indirect energy sources. Energy relations i.e. energy use efficiency, energy productivity and specific energy were calculated using the following formulae based on crop output and the energy equivalent of inputs and outputs [63-64].

2.6 Data Analysis

Two years of data on crop biomass, output energy, net energy return, and energy relations were pooled and analysed using the pooled Analysis of variance in a Split-Plot Design [65]. F-test was used to assess variance homogeneity. The treatment was compared using the least significant difference at p=.05 achieved in the analysis, which is represented by alphabetical letters.

3. RESULTS AND DISCUSSION

Crop production requires energy input i.e. the use of energy in land preparation, planting, fertilizer application, irrigation, intercultural operations, harvesting, and postharvest operations. In this study, the quantity of farm machinery, diesel, irrigation water and pesticides were equally used for all treatments, hence these inputs were considered as common inputs. Varying levels of plant spacing and NPK fertilizers in different treatment combinations caused the variations among the inputs of seed and fertilizers and are also responsible for differential human labor input requirements for transplanting, fertilizer application, harvesting, and packaging. Therefore, the component of seed, fertilizers and labor inputs are denoted as variable inputs.

The source-specific input energy required for cape gooseberry cultivation with different plants spacing and NPK fertilizers presented in Table 3. Regardless of treatment, the input-wise energy share of various inputs for the cape gooseberry crop is depicted in Fig. 1. Diesel evidently accounts for the highest percentage of input energy (40.44%) followed by water (32%), fertilizers (19.28%), machinery (3.29%), labor (3.2%), and pesticides (3.2%). The energy share of the seed input was negligible (0.001%). The equivalent input energy requirements for farm machinery, diesel, water and pesticides were 687.06, 8446.50, 6732.00, and 324.00 MJ ha^{-1}, respectively. Fertilizers and human labor were some of the variable inputs that provided the large amount of energy, whereas seed input energy was minimal (<0.001 %) in all spacing and NPK fertilizer treatment combinations. The energy input for NPK fertilizer at 100:80:80, 80:60:60, and 60:40:40 kg ha^{-1} was estimated to be 7484, 5916, and 4348 MJ ha^{-1}, respectively. Labor input energy varied with plant spacing and NPK fertilizer treatment measured highest (721.30 MJ ha^{-1}) in 75 x 75 cm spacing with 100:80:80 NPK kg ha^{-1}, followed by 75 x 60 cm with 80:60:60 NPK kg ha^{-1} (719.34 MJ ha^{-1}) and was lowest in 90 x 75 cm spacing without NPK fertilizers (595.01 MJ ha^{-1}).

Table 4 shows the operation-by-operation input energy for cape gooseberry production with various plant spacings and NPK fertilizers. Regardless of the treatments, irrigation received the highest share of input energy (50.67 %), followed by field preparation (25.64 %), fertilizer application (19.32 %) plant protection (2.71 %), harvesting and packaging (1.02 %), weeding (0.25 %), transplanting (0.1 %), and the lowest (0.06 %) in nursery raising (Fig. 2). Maximum input energy needed for irrigation i.e. 10584.08 MJ ha^{-1} followed by field preparation (5355.72 MJ ha^{-1}) which was constant throughout the treatments. Input energy for fertilizers application varied with the doses of NPK fertilizers. For fertilizer applications of 100:80:80, 80:60:60, and 60:40:40 NPK kg ha^{-1}, input energy was estimated to be 7495.76, 5927.76, and 4359.76 MJ ha^{-1}, respectively. The weeding and plant protection energy inputs were 52.95 and 565.32 MJ ha^{-1}, respectively. Plant spacing and NPK fertilizer treatment combinations affected input energy for harvesting, with the largest (244.55 MJ ha^{-1}) coming from 75 x 75 cm spacing with 100:80:80 kg ha^{-1} NPK fertilizers and the lowest coming from 90 x 75 cm spacing without fertilizers (163.36 MJ ha^{-1}).

Previous studies on various crops also show that energy inputs requirement varied with the type of inputs used. In strawberry [66], irrigation energy consumed the highest (34.3%) of total energy followed by nitrogen fertilizer (31.6%). Chemical fertilizers have consumed maximum energy in apple production [67]. In a maize-wheat-green gram cropping system percentage contribution of input energy resources evaluated with the highest by crop residues application, followed by fertilizers, diesel and water, plant protection chemicals and seeds, human labor, and the least by machinery [68]. In soybean, the biggest share in total energy input was obtained by electricity (45.06%), followed by chemical fertilizer (19.83%), and diesel fuel energy inputs (14.00%), respectively [69].

The use of a higher proportion of diesel fuel and water input energy in this study emphasizes that reducing diesel fuel consumption and water for irrigation usage is crucial for input energy reduction to a great extent. Limited availability of electricity-based irrigation source and canal irrigation in indo-Gangetic plains of India posed to rampant use of diesel for groundwater exploration for irrigation purposes. As a result of global climate change, precipitation may be uncertain in some regions of the world and surface, as well as ground water, may suffer increased losses due to evaporation, reducing the water available for irrigation; therefore, there is urgent need for the most efficient use of existing water resources and to give top priority to water-saving technologies [70]. A saving in diesel fuel by alternative input sources viz. electricity operated water lifting-devices efficient use of irrigation water through modern methods of irrigation systems with high efficiency (viz. drip irrigation) is needed for water-saving.

The proportions of direct and indirect energy as well as renewable and non-renewable energy needed in cape gooseberry production, differ from one another and vary greatly according to the treatments (Table 5). Regardless of treatment, the energy share of direct and indirect energy, as well as renewable and non-renewable energies in cape gooseberry production is depicted in Fig. 3. The percentage contribution of direct and indirect energy to total input energy was 75.87 and 24.13 %, respectively, regardless of the treatment. Non-renewable renewable energy had a substantially bigger chunk of the total input energy than renewable energy (35.44% against 64.56%, respectively). Each type of renewable energy also has special advantages that make it uniquely suited to certain applications [71]. Renewable technologies are considered as clean sources of energy and optimal use of these resources minimize environmental impacts, produce minimum secondary wastes and are sustainably based on current and future economic and social societal needs [72]. The use of renewable energy offers a range of exceptional benefits. Panwar et al. [73] emphasizes that use of renewable energy is beneficial as a boost to local and regional component manufacturing industries.

Table 3. Equivalent input energy (MJ ha^{-1}) of various physical inputs in cape gooseberry cultivation with varying agronomic manipulation

Treatment	Machinery	Fertilizer	Seed	Labor	Irrigation water	Diesel	Chemical
S_1F_0	687.06	-	0.200	637.96	6732.00	8446.50	324.00
S_1F_1	687.06	4348.00	0.200	693.06	6732.00	8446.50	324.00
S_1F_2	687.06	5916.00	0.200	714.24	6732.00	8446.50	324.00
S_1F_3	687.06	7484.00	0.200	719.34	6732.00	8446.50	324.00
S_2F_0	687.06	-	0.175	622.27	6732.00	8446.50	324.00
S_2F_1	687.06	4348.00	0.175	675.41	6732.00	8446.50	324.00
S_2F_2	687.06	5916.00	0.175	696.59	6732.00	8446.50	324.00
S_2F_3	687.06	7484.00	0.175	721.30	6732.00	8446.50	324.00
S_3F_0	687.06	-	0.150	595.01	6732.00	8446.50	324.00
S_3F_1	687.06	4348.00	0.150	654.23	6732.00	8446.50	324.00
S_3F_2	687.06	5916.00	0.150	670.31	6732.00	8446.50	324.00
S_3F_3	687.06	7484.00	0.150	692.08	6732.00	8446.50	324.00

Plant spacing: S_1=75 x 60 cm, S_2=75 x75 cm and S_3=90 x 75 cm; NPK fertilizers: F_0= no NPK fertilizers, F_1=60:40:40 kg $N:P_2O_5:K_2O$ ha^{-1}, F_2=80:60:60 kg $N:P_2O_5:K_2O$ ha^{-1} and F_3=100:80:80 kg $N:P_2O:K_2O$ ha^{-1}

Table 4. Operation-wise input energy (MJ ha^{-1}) in cape gooseberry cultivation with varying agronomic manipulation

Treatment	Field preparation	Nursery raising	Transplanting	Fertilization	Irrigation	Weeding	Plant protection	Harvesting & packaging
S_1F_0	5355.72	11.960	26.28	-	10584.08	52.95	565.32	231.41
S_1F_1	5355.72	11.960	26.28	4359.76	10584.08	52.95	565.32	223.37
S_1F_2	5355.72	11.960	26.28	5927.76	10584.08	52.95	565.32	237.49
S_1F_3	5355.72	11.960	26.28	7495.76	10584.08	52.95	565.32	241.02
S_2F_0	5355.72	11.935	21.18	-	10584.08	52.95	565.32	176.50
S_2F_1	5355.72	11.935	21.18	4359.76	10584.08	52.95	565.32	212.78
S_2F_2	5355.72	11.935	21.18	5927.76	10584.08	52.95	565.32	226.9
S_2F_3	5355.72	11.935	21.18	7495.76	10584.08	52.95	565.32	244.55
S_3F_0	5355.72	11.910	17.65	-	10584.08	52.95	565.32	163.36
S_3F_1	5355.72	11.910	17.65	4359.76	10584.08	52.95	565.32	198.66
S_3F_2	5355.72	11.910	17.65	5927.76	10584.08	52.95	565.32	205.72
S_3F_3	5355.72	11.910	17.65	7495.76	10584.08	52.95	565.32	222.39

Plant spacing: S_1=75 x 60 cm, S_2=75 x75 cm and S_3=90 x 75 cm; NPK fertilizers: F_0= no NPK fertilizers, F_1=60:40:40 kg $N:P_2O_5:K_2O$ ha^{-1}, F_2=80:60:60 kg $N:P_2O_5:K_2O$ ha^{-1} and F_3=100:80:80 kg $N:P_2O:K_2O$ ha^{-1}

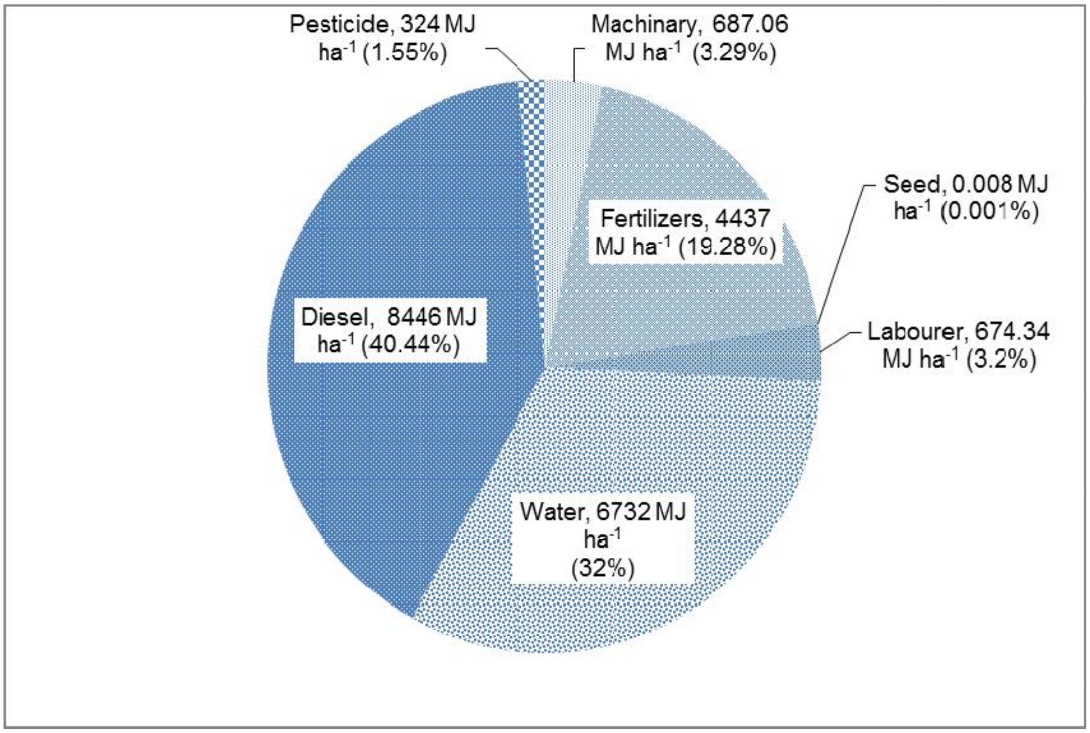

Fig. 1. Source-wise input energy (%) in cape gooseberry cultivation irrespective of different agronomic manipulations

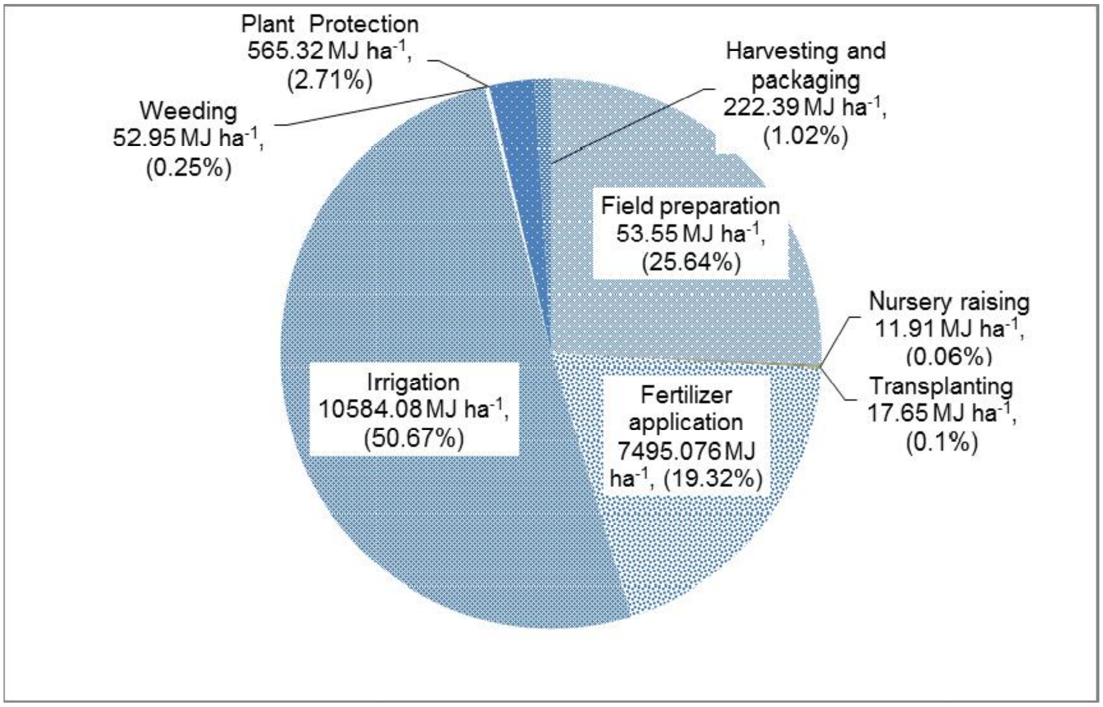

Fig. 2. Operation-wise input energy (%) in cape gooseberry cultivation irrespective of different agronomic manipulations

Table 5. Renewable and non-renewable input energy (MJ ha^{-1}) in cape gooseberry cultivation with agronomic manipulation

Treatment	Direct energy		Indirect energy		Renewable energy		Non-renewable energy	
	Quantity	%	Quantity	%	Quantity	%	Quantity	%
S_1F_0	15178.50	90.20	1011.26	25.24	7370.16	43.80	9457.56	56.20
S_1F_1	15871.56	74.76	5359.26	30.36	7425.26	34.97	13805.56	65.03
S_1F_2	15892.74	69.64	6927.26	34.83	7446.44	32.63	15373.56	67.37
S_1F_3	15897.84	65.17	8495.26	6.01	7451.54	30.55	16941.56	69.45
S_2F_0	15800.77	93.99	1011.24	25.26	7354.45	43.75	9457.56	56.25
S_2F_1	15853.91	74.74	5359.24	30.38	7407.59	34.92	13805.56	65.08
S_2F_2	15875.09	69.62	6927.24	34.82	7428.77	32.58	15373.56	67.42
S_2F_3	15899.80	65.18	8495.24	6.02	7453.48	30.55	16941.56	69.45
S_3F_0	15773.51	93.98	1011.21	25.29	7327.16	43.65	9457.56	56.35
S_3F_1	15832.73	74.71	5359.21	30.41	7386.38	34.85	13805.56	65.15
S_3F_2	15848.81	69.59	6927.21	34.87	7402.46	32.50	15373.56	67.50
S_3F_3	15870.58	65.13	8495.21	6.01	7424.23	30.47	16941.56	69.53

Plant spacing: S_1=75 x 60 cm, S_2=75 x75 cm and S_3=90 x 75 cm; PK fertilizers: F_0= no NPK fertilizers, F_1=60:40:40 kg N:P_2O_5:K_2O ha^{-1}, F_2=80:60:60 kg N:P_2O_5:K_2O ha^{-1} and F_3=100:80:80 kg N:P_2O:K_2O ha^{-1}

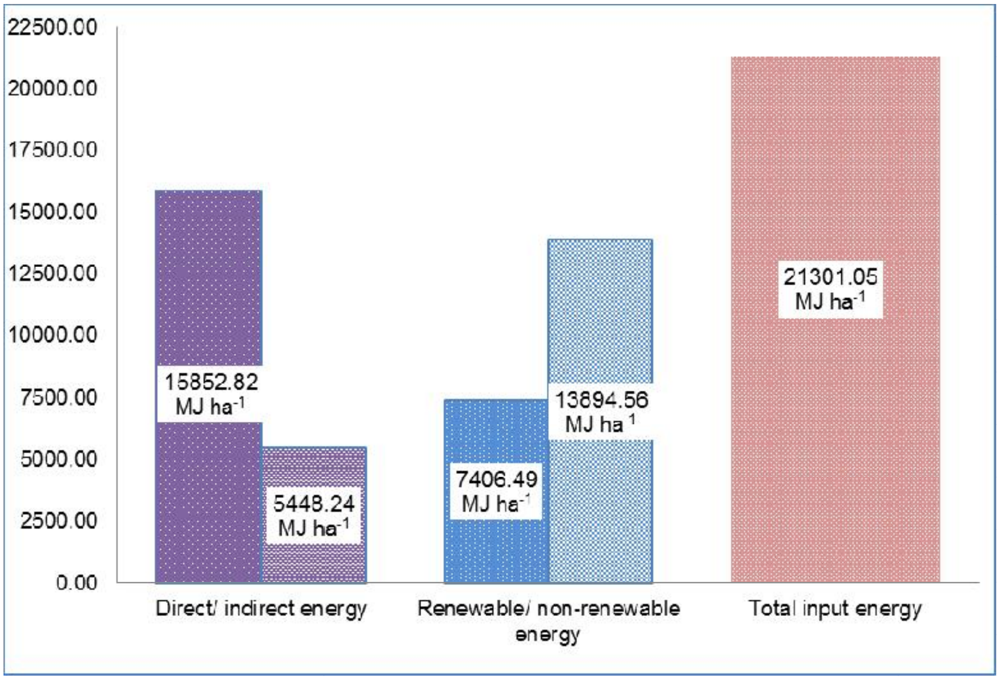

Fig. 3. Share of direct and indirect renewable and non-renewable input energy in cape gooseberry cultivation irrespective of agronomic manipulations

The total energy input required for cape gooseberry production with varied agronomic manipulations ranged from 16893.50 MJ ha^{-1} to 24566.54 MJ ha^{-1} depending on plant spacing and NPK fertilizer (Fig. 4). Crops grown at 75x75 cm spacing with 100:80:80 kg ha^{-1} NPK required the most energy input (24395.04 MJ ha^{-1}) followed by 75 x 60 cm spacing with the same NPK level (24393.10 MJ ha^{-1}), and crop grown at 90 x 75 cm spacing without fertilizers required the least (24393.10 MJ ha^{-1}. All of the treatments used the same machinery, diesel, irrigation water and pesticides, therefore the differences in total input.

Cape gooseberry being a herbaceous crop with a longer crop duration of about 8 months it requires an adequate supply of soil moisture for optimum growth and development that largely meet out by supplementary irrigation for which a sizable amount of water as well diesel fuel for water lifting device operation were used that ultimately constituted maximum share of input energy for irrigation. It is therefore obvious that the operation-wise energy consumption of crops varied with the type of source input used, growing environment as well as energy-efficient production practices being adopted for a particular crop production system. Similar energy consumption patterns have been reported in crops wherein irrigation, fertilizer application and field preparations are reported to be a major part of input energy consumption [51-55]. In the maize-wheat-green gram cropping system, the highest energy was consumed in the residue application followed by fertilizer management, irrigation, land preparation and sowing, harvesting and threshing, herbicide application, plant protection and the least was by inter-culturing operation [68].

Fruit and crop residue yields of cape gooseberry were significantly influenced by planting distance and NPK fertilizer application rates (Table 6). Plants established at closest spacing (75 x 60 cm) resulted into highest fruit yield (8.48 t ha^{-1}), residue yield (5.07 t ha^{-1}) as well as total biomass production (13.55 t ha^{-1}) followed by the spacing of 75 x75 cm (8.39 t ha^{-1} fruits, 4.65 t ha^{-1} crop residue and 13.04 t ha^{-1} total biomass) and the lowest was in plant spacing at 90 x 75 cm (7.39 t ha^{-1} fruit 4.18 t ha^{-1} crop residue and ha^{-1} total biomass). Among NPK treatments, maximum fruit yield (9.27 t ha^{-1}), crop residue yield (5.59 t ha^{-1}) and total biomass (14.86 t ha^{-1}) was observed at 100:80:80 kg ha^{-1} NPK fertilizes followed by 80: 60: 60 kg ha^{-1} NPK fertilizes (9.16 t ha^{-1} fruit, 4.89 t ha^{-1} crop residue and 14.05 t ha^{-1} total biomass) and was minimum with unfertilized control plot (6.02 t ha^{-1} fruits, 3.35 t ha^{-1} crop residue and 9.37 t ha^{-1} total biomass). Thus, crop management at 75 x 75 cm spacing with 100:80:80 kg ha^{-1} NPK fertilizers resulted in highest fruit yield of cape gooseberry (10.38 t ha^{-1}), followed by 75 x 60 cm with same NPK level (9.77 t ha^{-1}) and was lowest (5.56 t ha^{-1}) at 90 x 75 cm spacing without fertilizers. Crop plant residue was highest at 75 x 60cm with 100:80:80 kg ha^{-1} NPK fertilizers (6.23 t ha^{-1}) followed by 75 x 75 cm spacing with 100:80:80 kg ha^{-1} NPK fertilizers (5.52 t ha^{-1}) and was lowest at 90 x 75 cm spacing without fertilizers (2.93 t ha^{-1}). Total crop biomass was maximum (16.00 t ha^{-1}) with treatment combination of 75 x 60 cm spacing with 100:80:80 kg ha^{-1} NPK fertilizers, followed by 75 x 75 cm spacing with 100:80:80 kg/ha NPK fertilizers (15.90 t ha^{-1}) and was lowest in the treatment combination of 90 x 75 cm spacing without NPK fertilizers (8.49 t ha^{-1}).

The growth of the crop is influenced by various factors such as climate, soil fertility, growing methods etc; among them, soil fertility and plant spacing are of immense importance and are more responsible for realizing the higher biomass production. Higher plant population by adopting closer planting distance in our study is attributed to increased vegetative growth that enhances total biomass production per unit area. Higher vegetative growth and fruit yield constituting total crop biomass of crop have been reported with increased planting density in cape gooseberry [73,74], tomato [75,76], strawberry [77,78]. Nitrogen, phosphorus and potassium are considered essential primary nutrients and are required in large quantities by plants. The increased crop biomass is attributed to the increased availability of N, P and K with elevated soil fertility levels as applied nutrients help in vigorous growth of the plant. Similar effects of NPK fertilization on productivity in cape gooseberry were also reported in Indian conditions [71,79,80]. Increased output energy with higher doses of NPK fertilizers in our study is attributed to the higher total biomass yield as the bio-energy energy outputs are directly estimated from the crop outputs.

The output and net energy return of cap gooseberry as a function of agronomic interventions (plant spacing and NPK fertilizers) are shown in Table 6. Crops planted with the closest spacing (75 x 60 cm) yielded the highest gross output energy (66807.25 MJ ha$^{-1)}$ and net energy return (45531.80 MJ ha^{-1}) followed by 75 x 75 cm (62466.00 MJ ha^{-1} output energy and 41213.81 MJ ha^{-1} net energy). The widest spacing (90 x 75 cm) yielded the lowest output energy (55816.00 MJ ha^{-1}) and net energy return (34585.02 MJ ha^{-1}). NPK fertilizers had a significant impact on gross and net output energy returns, with 100:80:80 kg NPK ha-1 yielding the greatest (73519.33 MJ ha^{-1} and 49195.88 MJ ha^{-1}, respectively) followed by 80:60: 60 kg NPK ha^{-1} (66304.00 MJ ha^{-1} output energy and 43561.16 MJ ha^{-1} net energy return). Without NPK fertilizers, the minimum output energy (44965.00 MJ ha^{-1}) and net energy return (28182.87 MJ ha^{-1}) were observed. Crops planted at 75 x 60 cm spacing with 100:80:80 kg ha^{-1} NPK fertilizers had the greatest overall gross and net energy output (80863 and 56529.91MJ ha^{-1}, respectively) across crop management systems with variable plant spacing and NPK fertilizers, followed by 75 x 75 cm spacing with the same NPK level (74922 and 50590.51 MJ ha^{-1}, respectively). With 90 x 75cm spacing and no fertilizers the lowest gross energy output and net energy return were obtained (39864.00 MJ ha^{-1} and 23113.01 MJ ha^{-1}, respectively).

Energy use efficiency, energy productivity, energy profitability and human energy profitability of cape gooseberry production with plant spacing and fertilizer management are presented in Table 7. Close planting, i.e. 75 x 60 cm, yielded the highest value of energy use efficiency (3.13), energy productivity (0.40), energy profitability (2.13) and human energy profitability (96.13 MJ-1) while widest planting (90 x 75 cm) yielded the lowest value of energy use efficiency (2.62), energy productivity (0.38 kg MJ^{-1}), energy profitability (1.62) and human energy profitability (84.95 MJ labor^{-1}). Energy intensity was maximum with widest spacing of 90 x 75 cm (2.89) while it was minimum with closet spacing (2.52 MJ kg^{-1}). Crops grown with various levels of NPK fertilizer tend to increase energy efficiency, energy profitability, energy productivity and human energy profitability, whereas crop grown without NPK fertilizers have the highest energy intensity. NPK at 100:80:80 kg ha^{-1} demonstrated significantly higher energy use efficiency (2.99) and energy profitability (1.99 MJ ha^{-1}). The highest energy productivity was achieved with NPK at 80:60:60 kg ha^{-1} (0.40). The highest human energy profitability (103.29 MJ laborer^{-1}) was achieved with an NPK level of 100:80:80 kg ha^{-1}. Crops grown without NPK fertilizers had the lowest energy use efficiency (2.65), energy profitability (1.65 MJ ha^{-1}) and energy productivity (0.36 MJ kg^{-1}) and energy profitability (60.83 MJ labourer^{-1}). Crops grown without NPK fertilizers had the highest energy intensity (2.82 MJ kg^{-1}) while crops grown with the highest level of NPK fertilizers had the lowest (2.69 MJ kg^{-1}).

Among the different treatment combinations, the crop raised at 75 x 60 cm spacing with 100:80:80 kg ha-1 NPK fertilizers had the highest energy use efficiency (3.32), energy profitability (2.32) and human energy profitability (112.41 MJ labor^{-1}) and the lowest in the crop raised at 90 x 75 cm spacing without NPK fertilizers (2.38, 1.38, and 67.00 MJ labor^{-1}, respectively). Energy productivity was highest (0.43 kg MJ^{-1}) when 75 x 75 cm spacing was used with 100:80:80 kg ha^{-1} NPK fertilizers and lowest (0.43 kg MJ^{-1}) when 90 x 75 cm spacing was used without fertilizers (0.33 MJ ha^{-1}).

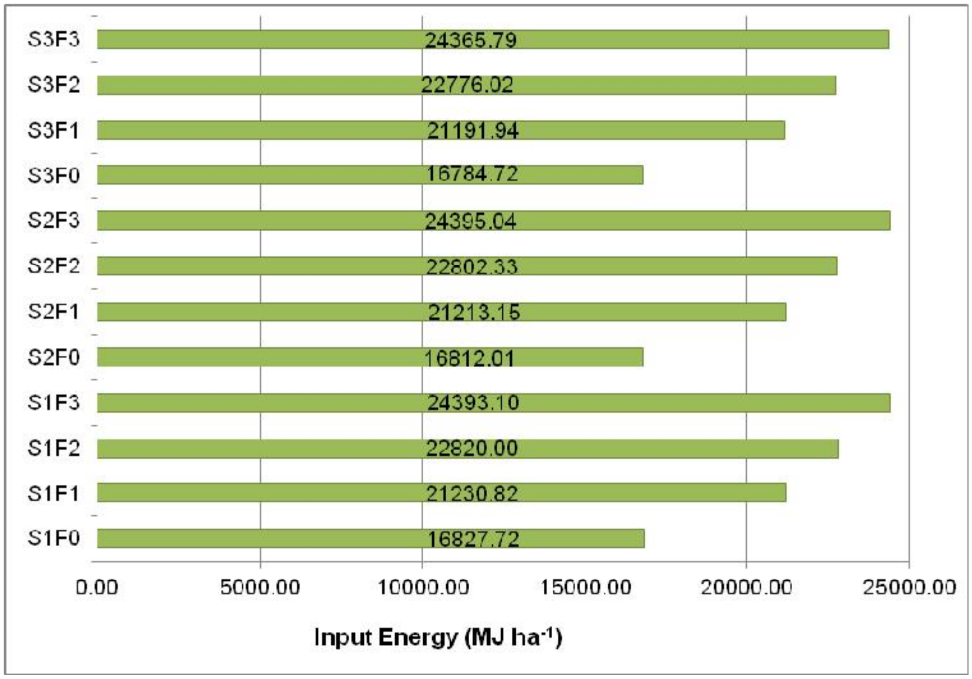

Fig. 4. Total energy inputs of cape gooseberry cultivation with varying agronomic manipulati

Table 6. Economic yield, by-product and total biomass production (t ha^{-1}), energy output and net energy return (MJ ha^{-1}) in of cape gooseberry cultivation with varying agronomic manipulation

Treatment	Economic yield (fruits)	By-product (crop residue)	Total biomass	Energy output	Net energy return
Spacing (S)					
S_1	8.48^{A}	5.07^{A}	13.55^{A}	66807.25^{A}	45531.80^{A}
S_2	8.39^{A}	4.65^{B}	13.04^{A}	62466.00^{B}	41213.81^{B}
S_3	7.39^{B}	4.18^{C}	11.57^{B}	55816.00^{C}	34585.02^{C}
NPK level (F)					
F_0	6.02^{C}	3.35^{C}	9.37^{D}	44965.00^{D}	28182.87^{D}
F_1	7.89^{B}	4.70^{B}	12.59^{C}	61997.33^{C}	40834.26^{C}
F_2	9.16^{A}	4.89^{B}	14.05^{B}	66304.00^{B}	43561.16^{B}
F_3	9.27^{A}	5.59^{A}	14.86^{A}	73519.33^{A}	49195.88^{A}
Spacing x NPK level					
S_1F_0	6.47^{F}	3.83^{E}	10.30^{D}	50593.00^{G}	33765.28^{G}
S_1F_1	8.26^{DE}	4.71^{C}	12.97^{C}	62794.00^{DEF}	41614.56^{D}
S_1F_2	9.41^{BC}	5.51^{B}	14.92^{B}	72979.00^{BC}	50217.44^{BC}
S_1F_3	9.77^{AB}	6.23^{A}	16.00^{A}	80863.00^{A}	56529.91^{A}
S_2F_0	6.02^{FG}	3.30^{F}	9.32^{E}	44438.00^{H}	27670.32^{H}
S_2F_1	7.86^{E}	4.75^{C}	12.61^{C}	62434.00^{DEF}	41270.28^{DE}
S_2F_2	9.30^{BCD}	5.04^{BC}	14.34^{B}	68070.00^{CD}	45324.16^{CD}
S_2F_3	10.38^{A}	5.52^{B}	15.90^{A}	74922.00^{AB}	50590.51^{ABC}
S_3F_0	5.56^{G}	2.93^{F}	8.49^{E}	39864.00^{H}	23113.01^{H}
S_3F_1	7.56^{E}	4.64^{D}	12.20^{C}	60764.00^{EF}	39617.95^{DEFG}
S_3F_2	8.76^{CD}	4.12^{E}	12.89^{C}	57863.00^{F}	35141.89^{EFG}
S_3F_3	7.67^{E}	5.02^{BC}	12.69^{C}	64773.00^{DE}	40467.22^{DEF}

Superscripted similar letters on the values indicate non-significant difference among the treatments.
Plant spacing: S_1=75 x 60 cm, S_2=75 x75 cm and S_3=90 x 75 cm; NPK fertilizers: F_0= no NPK fertilizers, F_1=60:40:40 kg $N:P_2O_5:K_2O$ ha^{-1}, F_2=80:60:60 kg $N:P_2O_5:K_2O$ ha^{-1} and F_3=100:80:80 kg $N:P_2O:K_2O$ ha^{-1}

Table 7. Energy input and output relationship in cape gooseberry with varying agronomic manipulation

Treatment	Energy use efficiency	Energy profitability	Energy productivity (kg MJ^{-1})	Energy intensity (MJ kg^{-1})	Human energy profitability (MJ laborer^{-1})
Spacing (S)					
S_1	3.13^{A}	2.13^{A}	0.40^{A}	2.52^{B}	96.12^{A}
S_2	2.92^{B}	1.92^{B}	0.37^{B}	2.57^{B}	91.36^{B}
S_3	2.62^{C}	1.62^{C}	0.38^{B}	2.89^{A}	84.95^{C}
NPK level (F)					
F_0	2.68^{C}	1.68^{C}	0.38^{B}	2.80^{A}	72.57^{C}
F_1	2.93^{B}	1.93^{B}	0.41^{A}	2.68^{A}	91.97^{B}
F_2	2.92^{B}	1.92^{B}	0.37^{B}	2.49^{B}	95.41^{B}
F_3	3.02^{A}	2.02^{A}	0.38^{B}	2.67^{AB}	103.29^{A}
Spacing x NPK level					
S_1F_0	3.01^{BC}	2.01^{BC}	0.38^{EF}	2.60^{CDE}	79.30^{FG}
S_1F_1	2.96^{C}	1.96^{C}	0.39^{DE}	2.56^{CDE}	90.60^{DE}
S_1F_2	3.21^{AB}	2.21^{AB}	0.41^{AB}	2.42^{DE}	102.18^{BC}
S_1F_3	3.32^{A}	2.32^{A}	0.40^{CD}	2.49^{CDE}	112.41^{A}
S_2F_0	2.65^{DE}	1.65^{EF}	0.36^{G}	2.79^{BC}	71.41^{GH}
S_2F_1	2.95^{C}	1.95^{C}	0.37^{FG}	2.69^{CD}	92.44^{DE}

Treatment	Energy use efficiency	Energy profitability	Energy productivity (kg MJ^{-1})	Energy intensity (MJ kg^{-1})	Human energy profitability (MJ laborer^{-1})
S_2F_2	2.99^{BC}	1.99^{BC}	0.41^{BC}	2.45^{DE}	97.72^{CD}
S_2F_3	3.08^{ABC}	2.08^{BC}	0.43^{A}	2.34^{E}	103.87^{BC}
S_3F_0	2.38^{F}	1.38^{G}	0.33^{AH}	3.01^{AB}	67.00^{H}
S_3F_1	2.87^{CD}	1.87^{CDE}	0.36^{G}	2.80^{AB}	92.88^{DE}
S_3F_2	2.55^{EF}	1.55^{FG}	0.39^{EF}	2.59^{CDE}	86.32^{EF}
S_3F_3	2.66^{DE}	1.66^{DEF}	0.32^{H}	3.17^{A}	93.59^{DE}

Superscripted similar letters on the values indicate non-significant difference among the treatments.
Plant spacing: S_1=75 x 60 cm, S_2=75 x75 cm and S_3=90 x 75 cm; NPK fertilizers: F_0= no NPK fertilizers, F_1=60:40:40 kg N:P_2O_5:K_2O ha^{-1}, F_2=80:60:60 kg N:P_2O_5:K_2O ha^{-1} and F_3=100:80:80 kg N:P_2O:K_2O ha^{-1}

4. CONCLUSION

The total energy consumption in cape gooseberry production in a Sodic soil at varying plant spacing and NPK fertilizers was recorded ranged from 16893.50 MJ ha^{-1} to 24566.54 MJ ha^{-1}. On average, 75.87% of the total energy input used in cape gooseberry production was direct, while the contribution of indirect energy was 24.13 %. Also, the shares of renewable and non-renewable energy inputs were 35.44 and 64.56 %, respectively. Diesel fuel energy was the energy input item that occupied the biggest share within all the energy inputs followed by water and fertilizers, respectively. Raising cape gooseberry at 75 x 75 cm with 100:80:80 kg ha^{-1} NPK fertilizers yielded maximum fruit yield, while total biomass production is realized at maximum with 75 x 60 cm with 100:80:80 kg ha^{-1} NPK fertilizers. The energy output as well as net energy return tend to be highest (56529.91 MJ ha^{-1}) in close plant spacing (75 x 60 cm) with 100:80:80 kg ha^{-1} NPK fertilizers followed by 75 x 75 cm spacing with the same NPK doses (50590.51 MJ ha^{-1}). Plant spacing of 75 x 60 cm supplemented with a high dose of NPK fertilizes at 100:80:80 kg ha^{-1} resulted in highest energy use efficiency and profitability. High diesel fuel and water energy consumption in our study were mainly due to the use of diesel-irrigation pumps, non-availability of low price electricity operated water-lifting devices and large water quantities needed for irrigation of the crop. This study demostrated that a reduction in diesel and water consumption is indispensable for energy savings and lowering of environmental risks for sustainable crop production. Since the prevailing irrigation system leads to unconscious over-usage of water and diesel fuel, reducing diesel fuel and water is important for proper input energy balancing. Based on energy budgeting, plant spacing at 75 x 60 cm and 75 x 75 cm with NPK fertilizer at 100:80:60 kg ha^{-1} N, P_2O_5 and K_2O are recommended in Sodic soils for maximum biomass production of cape gooseberry with higher input energy efficiency.

DISCLAIMER

The products used for this research are commonly and predominantly used products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but only for the advancement of scientific knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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