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Energy Budgeting and Efficiency Analysis of Organic Cotton: A DEA Approach

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ABSTRACT

Background: Cotton (*Gossypium hirsutum* L.) is crop of economic importance in global and national scale. India is the greatest producer of quality cotton, the third largest exporter and the second largest consumer. Conventional cotton farming creates environmental pressures and negative impact on public health. Organic farming is the sustainability option in cotton production. Cotton is the energy intensive crop, which uses high amount of input energy to produce seed cotton. Hence, energy budgeting is highly essential for better energy utilization and resource conservation and also measuring the input use efficiency of a farm/ agronomic practices is vitally important in present day Indian agriculture.

Methods: Sensing the economic importance of cotton, ten number of eco-friendly, ecologically safe organic nutrient management (ONM) practices were framed and field experiment was conducted in split plot design with two main plots (M) and five subplots (S) and replicated thrice. The direct and indirect energy used in different ONM practices were computed and energy coefficients were computed from energy equivalents and that has been used as inputs to generate efficiency coefficients by using an input oriented DEA approach.

Result: Energy budgeting on field operation basis reported that, the field preparation and irrigation operation uses most of the energy (in non-renewable forms) which needs attention and there is the scope to find alternative energy conservation systems. Results on input use efficiency reported that the ONM practice, double green manuring followed by cotton and application of well decomposed poultry manure and foliar application of fermented fish extract at 5% concentration at 25 and 35 DAS are 100% efficient in terms of technical CRS, technical VRS, scale, allocative and cost efficiencies. This organic nutrient management practice would produce optimum output from the least amount of input and would be ideal for sustainable cotton production.

Key words: Allocative, Cost, Efficiency, Energy, Nutrient management, Organic cotton.

INTRODUCTION

Cotton (*Gossypium hirsutum* L.), grown for fibre in 76 nations, is the world's most traded commodity and 100 million individuals are involved in cotton cultivation and processing. Cotton contributes around 25-35% of total fibre consumption worldwide (Singh *et al*., 2021). Globally, cotton was cultivated in area of about 33.48 million hectares with an average production of 113.11 million bales of 170 kg. India is the greatest producer of quality cotton, the third largest exporter and the second largest consumer. In India, the crop occupies 13.48 million hectares with a production of 36.5 million bales of 170 kg (32% share of global production)(Anonymous, 2022a, Anonymous, 2022b). As a result, cotton is a critical crop for the Indian agricultural society and economy.

Cotton is highly input intensive which use high quantities of synthetic fertilizers, chemical pesticides and human and machine power. It causes environmental pressures such as soil erosion, water and air pollution, greenhouse gas emissions, biodiversity and ecosystem services loss and a negative impact on public health. Organic farming is the sustainability option in cotton production. Organic cotton production, organic apparel demand and employment prospects have recently seen remarkable gains (Asif, 2017). According to organic cotton statistics, India (1.23 million tonnes) produces 51% of global organic cotton output (2.43 million tonnes). In India, more than 90% of organic cotton production was concentrated in states of Madhya Pradesh (0.38 Mt), Odisha (0.11 Mt), Maharashtra (0.19 Mt), Gujarat (0.08 Mt) and Rajasthan (0.06 Mt) (Anonymous, 2022b). Indian government also takes lead steps in organic cotton cultivation through ICAR-CICR, NFSM and union budget

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2023-24. Sensing the economic importance of cotton, eco-friendly, ecologically safe, low cost technologies, resilient genetics and better agronomic approaches are needed to sustainably enhance cotton production.

Cotton is the energy intensive crop, which uses high amount of input energy to produce seed cotton. Energy budgeting is highly essential for better energy utilization and resource conservation. Each input is unique and has unique use efficiency based on environmental conditions and agronomic practices. Hence, measuring the input use efficiency of a farm/agronomic practices is vitally important in present day Indian agriculture. Energy auditing and budgeting is a welcoming concept which clearly projects the high energy usage of particular input/operation and aids to segregate and visualize the possible way to attain maximum input utilization. Energy budgeting also paves the way to input optimization and reduction or to find alternative like less/renewable energy inputs (Imran *et al*., 2020).

Organic farming, though provide a sustainable solution, it also uses organic source of inputs in higher quantities. Hence, measuring the efficiency of inputs in terms of technical, allocative and cost basis will lead to attain maximum output from minimum input and input optimization. The main objective of this research paper is to study the operation-wise energy budgeting and efficiency of different organic nutrient management practices (ONM) on cotton production (Singh *et al*., 2021).

MATERIALS AND METHODS

Study area

The present study was experimented during June 2022 to February 2023 in *kharif* season (winter irrigated cotton) at Tamil Nadu Agricultural University (TNAU), Coimbatore situated at 11°N latitude and 76.9°E longitude to study the effect of different organic nutrient management practices on cotton production.

Experimental details

The experiment was laid in split plot statistical design with two main plots (M) and five subplots (S) and replicated thrice. Main plots were constituted with green manuring treatments (single and double green manuring) and subplots with organic nutrient management (ONM) practices *viz*., vermicompost, poultry manure, neem cake and farm yard manure (FYM) and foliar applications with fermented fish extract (FFE) and *panchagavya*. Sunnhemp (*Crotalaria juncea*) was chosen as the green manure crop. The treatments are as follows, single green manuring (SGM) followed by cotton + intercropping (M_1) and double green manuring (DGM) followed by cotton (M_2); vermicompost + FFE 5% (S_1), well decomposed poultry manure + FFE 5% (S_2), neem cake + FFE 5% (S_3), FYM 12.5t/ha + *panchagavya* 3% (S_4) and control (S_5).

Single green manuring

This method refers to growing of green manure and *insitu* incorporation of sunnhemp just before the flowering stage.

Double green manuring

DGM refers to growing of sunnhemp in the field and incorporated *in situ* and again growing of sunnhemp in the same field and incorporated.

ONM practices

After *in situ* incorporation the field was left undisturbed for a week to identify the nitrogen contribution (soil available nitrogen by Subbaih and Asija, 1956 method) from green manuring treatments (M_1 and M_2) (Table 1). Land preparation for cotton has been carried out and required quantities of respective organic manures were applied after deducting the N contribution from green manure and cotton seeds were sown. The organic source of nutrients was applied based on nitrogen (N) content (%) in organic manures (Table 2 and 3). The initial soil available nitrogen content was recorded to be 197.2 kg/ha (low N status).

Seeds

CO 17 (Coimbatore 17) compact cotton variety released by TNAU in 2020 was used in this field trial. It is a short duration (125-135 days), synchronized boll maturity, zero monopodia and suitable for high density planting (Gunasekaran *et al*., 2020). Vamban 11 (VBN 11) blackgram variety (70-75 days) was used as intercrop in single green manuring treatmentin 1:1 ratio. The green manure seeds sunnhemp was mixed variety. The seeds *viz*., cotton, blackgram and sunnhemp were procured from Department of Cotton, Department of Pulses and Central Farm Unit, respectively from TNAU, Coimbatore.

Agronomic practices

Cotton seeds were sown in ridges and furrows with spacing of 60 cm × 15 cm. Blackgram was sown 7 days after cotton sowing at 10 cm plant spacing on other side of the ridges. Cotton was harvested in three pickings, first picking at first fortnight of January 2023, second and third picking at 15 days intervals. Blackgram was harvested at first fortnight of December 2022.

Energy budgeting

The inputs used in each ONM practices *viz*., human power, animal power, diesel, machineries, organic manures, bio-fermented liquids and electricity *etc*., were calculated operation-wise. The physical inputs were converted into energy inputs using respective energy equivalents of the particular input (Table 4). The energy input comprises direct energy inputs (operational) *viz*., human power, animal power, diesel and electricity and indirect inputs *viz*., seed, organic manures, fermented bio-liquids, biofertilizer and machineries. Opertaion-wise energy budgeting was done by summing up all the energy inputs used in particular operation.

Efficiency analysis

The efficiency of each decision making units (DMU's) (ONM practices) was analyzed using input-oriented data envelopment analysis (DEA) methods through the data envelopment analysis (Computer software) Program (DEAP version 2.0.) (Coelli, 1996). The scientists, Farrell (1957), Debreu's (1951) and Koopmans' (1951) postulated the modern efficiency analysis of a firm/practice/farm that comprises, technical efficiency (TE) (CRS and VRS), scale efficiency (SE), allocative efficiency (AE) and cost efficiency (CE). Technical efficiency is the capacity of a farm to generate the most possible output from a given set of inputs. On the other hand, the economic concept of "allocative efficiency" describes how various resources are combined to produce a variety of distinct outputs. Scale efficiency gives individuals the capacity to select the ideal resource size (Singh *et al*., 2021). Scale efficiency and economic efficiency are calculated using the following formula (1) and (2):

$$\text{SE of the ONM practice} = \frac{\text{TE of constant return scale}}{\text{TE of variable return scale}} \quad ....(1)$$

$$\text{TE} \times \text{AE} = \frac{\text{Economic}}{\text{Cost efficiency}} \quad ....(2)$$

DEA model is a non-parametric mathematical linear programming method. It optimises a scoring function known as efficiency, which is calculated as the ratio of a production unit's weighted sum of outputs to its weighted sum of inputs consumed. The model optimizes under the constraint that the value of the objective function attained with any of the production units in the model cannot be more than 1, indicating that efficient units will have a score of 1. One of the widely used efficiency analysis techniques is the DEA model. The inputs file (energy inputs and respective cost of inputs) (ONM-dta.txt) and instruction file (ONM-ins.txt) has been prepared and loaded in DEAP software (DEAP.000.txt) and output file (ONM-out.txt) on efficiency of ONM practices was downloaded. The energy inputs and output (GJ/ha) used in the DEAP are presented in Fig 1, 2 and 3.

Data visualization and projection was done using R studio programming software v.4.2.0 (Annonymous, 2022c) and Datawrappaer software.

RESULTS AND DISCUSSION

Energy budgeting of different ONM practices of organic cotton

Total input and output energy of various treatments are depicted in Fig 3. Among the green manuring treatments, higher amount of input energy was used by single green manuring (SGM) followed by cotton with intercropping (M_1) compared to double green manuring (DGM) followed by cotton (M_2). Among the ONM practices, besides control treatment, SGM-Cotton + IC and well decomposed poultry

Table 1: N contribution from green manuring treatments.

	Soil available N after 1 week of incorporation	Initial soil available N	N contribution from green manure incorporation	
Single green manuring	220.2	197.2	23 kg/ha	Soil sample collected before and after incorporation
Double green manuring	235.2	197.2	38 kg/ha	and soil available N was analyzed in laboratory

Table 2: Nutrient content (%) of organic source of nutrients used in the study.

	N (%)	P (%)	K (%)	Nutrient	Extract	Method	Reference	
Vermicompost	1.12	0.47	1.38	Total	Diacid	Microkjeldahl method	Humphries (1956)	Manure samples
Poultry manure	2.35	1.91	1.55	Nitrogen				are analysed
Farm yard manure	0.60	0.18	1.22	Total phosphorous	Triacid	Vanadomolybdate phosphoric yellow	Jackson (1973)	in laboratory
Neem cake	2.95	0.49	0.55			colour method		
Green manure	1.95	0.54	1.66	Total potassium	Triacid	Neutralised with ammonia and estimated using Flame photometer	Jackson (1973)	

Table 3: Quantity of organic source of nutrients applied.

	Total N requirement of winter irrigated cotton (kg/ha)	Qty of OM applied after deducting N contribution from GM treatments (t/ha)		Manures collection site
		M_1 (SGM)	M_2 (DGM)	
Vermicompost (S_1)	100	6.8	5.5	Vermicompost yard, Central Farm Unit, TNAU, Coimbatore
Poultry manure (S_2)	100	3.3	2.6	Poultry farm, Central Farm, TNAU, Coimbatore
Neem cake (S_3)	100	2.6	2.1	Procured from local cooperative store
Farm yard manure (S_4)	100	12.5	12.5	Central Farm Unit, TNAU, Coimbatore

manure at respective quantities with 5% FFE at 25 and 35 DAS recorded high amount of input energy and minimum output *viz*., M_1S_2 (14.3 GJ/ha and 69.4 GJ/ha) compared to double green manuring followed by cotton + poultry manure +FFE at 5% at 25 and 35 Das. This might be due to the energy equivalent of poultry manure and green manure is low (0.3 MJ/kg) when compared to other manures and compost and nutrient content of poultry manure is high in terms of NPK (2.35%, 1.91% and 1.55%, respectively), resulting in less organic manure application. Though the energy utilised for cotton cultivation is equally applicable for intercropping some special operations are needed to be performed for blackgram, includes seeds and sowing, gapfilling, thinning and harvest substatially increased the input energy usage the effect of synergism between double green manuring, poultry manure and FFE, resulting in increased nutrient contribution for cotton growth and development substantially increased growth and yield attributing characters of cotton and recorded superior yield over other treatments resulted in higher output energy. Several researchers reported that green manuring and application of poultry manure improves soil physical (Adeyemo *et al*., 2019), chemical and biological properties and also growth and yield of crops. Among total N requirement, application of poultry waste composts released around 51.3 percent N and had reduced nitrate leaching to deeper soil layers and increased nutrient availability to crop (Ntsoane, 2022). Scientists of organic farming reported that, green manure and poultry manure application leads to increased bacterial, fungal and actinomycetes population in soil which meanwhile increases soil enzyme activity (Zhen *et al*., 2014).

Operation-wise energy budgeting on different ONM practices of organic cotton

Operation-wise energy uses are presented in Fig 4. The irrigation operation used the most energy, followed by field preparation, application of manures and fertilizers, seeds

Table 4: Energy equivalents of inputs and outputs used in the study.

Inputs	Unit	Energy equivalent (MJ/unit)	References
Human power			
Adult man	Hours	1.96	Mittal *et al.* (1985)
Adult women	Hours	1.57	
Machinery			
Tractor	Hours	13.5	Mittal *et al.* (1985)
Cultivator	Hours	4.32	
Rotavator	Hours	6.48	
Diesel	Litres	56.31	
Animal (Medium sized)	Hours	10.10	
Seeds			
Sunnhemp	Kilograms	10	Mittal *et al.* (1985)
Cotton	Kilograms	25	
Blackgram	Kilograms	14.7	
Organic manures			
Farm yard manure	Kilograms	0.3	Mittal *et al.* (1985)
Poultry manure	Kilograms	0.3	
Vermicompost	Kilograms	0.61	Computed*
Neem cake	Kilograms	0.76	Computed*
Green manure (dry biomass)	Kilograms	0.3	
Biofertilizer	Kilograms	10	Mittal *et al.* (1985)
Fermented liquids			
Panchagavya	Litres	0.24	Devasenapathy *et al.* (2009)
Fermented fish extract	Litres	14.8	Computed*
Battery operated power sprayer (12V 8 Ah)	Hours	0.0036	Computed*
Electric motor	Hours	0.13	Computed*
Electricity	KWh	11.93	Mittal *et al.* (1985)
Output (Main)			
Kapas/Seed cotton	Kilograms	25	Mittal *et al.* (1985)
Lint yield	Kilograms	11.8	
Grain yield (Blackgram)	Kilograms	14.7	
By product			
Straw yield (cotton)	Kilograms	18	Mittal *et al.* (1985)

*The energy equivalents are computed based on inputs and process involved in the product production.

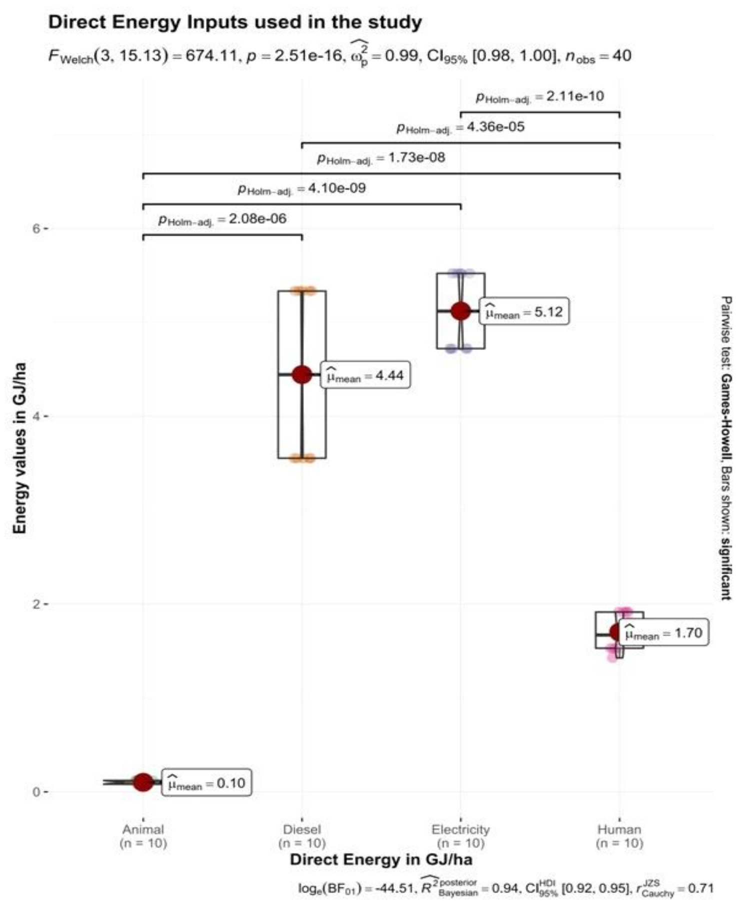
and sowing, intercultural operations, harvest and post-harvest activities, regardless of ONM practices.Water availability is one of the most important elements influencing land productivity and agricultural performance.Irrigation water is a critical input in agriculture, yet a large quantity of power is consumed only for irrigation.The findings indicate that rapid and visible actions are required to promote effective water systems and sustain irrigation input energy (Tarjuelo *et al*., 2015).

More than 25% of energy is consumed for field preparation, which involves a greater usage of nonrenewable resources such as diesel and machinery. In economic and environment terms, paying close attention to field preparation may limit the usage of nonrenewable forms of energy and contribute in the discovery of alternative options such as biofuel, electricity from renewable sources like wind, solar and hydel and solar and battery operated machines *etc.* (Yilmaz *et al*., 2005 and Balaji *et al*., 2023a). More than 80 per cent of energy was used by field preparation, irrigation and manure application operationsin non-renewable forms *viz*., diesel, electricity and machine power which needs special attention in present day context. Improving input use efficiency in such operations may conserve significant amount of energy that could be used for production of other crops/farm components.

Efficiency analysis of different ONM practices of organic cotton

The data on efficiency analysis and frequency distribution with efficiency levels of technical (CRS and VRS), scale efficiency, allocative efficiency and cost efficiency of all DMU's (ONM practices) are presented in Table 5 and 6.

When VRS were assumed, the efficiency scores for all ONM practises presented in Table 6 revealed that 80% of ONM practises were functioning with a technical efficiency level of 100%, while the remaining 20% had efficiency ratings ranging from 90% to 100%. When CRS is considered, 60% of the treatements had efficiency ratings of 100% and 20% of ONM practises were functioning between 90% and 100% and another 20% were working between 80% and 90% effiiency. Under the VRS paradigm, the mean technical efficiency for ONM practises was 0.999. This implies that average farms were producing output at 100% of their capacity. This also implies that there was only 1%



The box-violin plots are created using R studio programming software v 4.2.0. p-value <0.005 represent the significance.

Fig 1: Direct energy inputs used in the study (GJ/ha).

managerial inefficiency and 4% scale inefficiency (mean value: 96%). SE ratings indicate the farm's ability to select the optimal level of resources. However, 60% had a scale efficiency level between 90% and 100%. The distribution of scale efficiency is tilted towards right, indicating that almost three-fourths of ONM practises had efficiency in the 0.9 to 1 distribution level (Singh *et al*., 2021 and Balaji *et al*., 2023b).

Farrel (1957) believed that farmers arrange resources to achieve a specified level of output based on cost minimization (Wei *et al*., 2020). The costs of each inputs utilised were assessed using the actual prices paid by farmers to analyze allocative and cost efficiency. To assist the study, the input variables were combined to reduce the number of cost variables. According to the data in

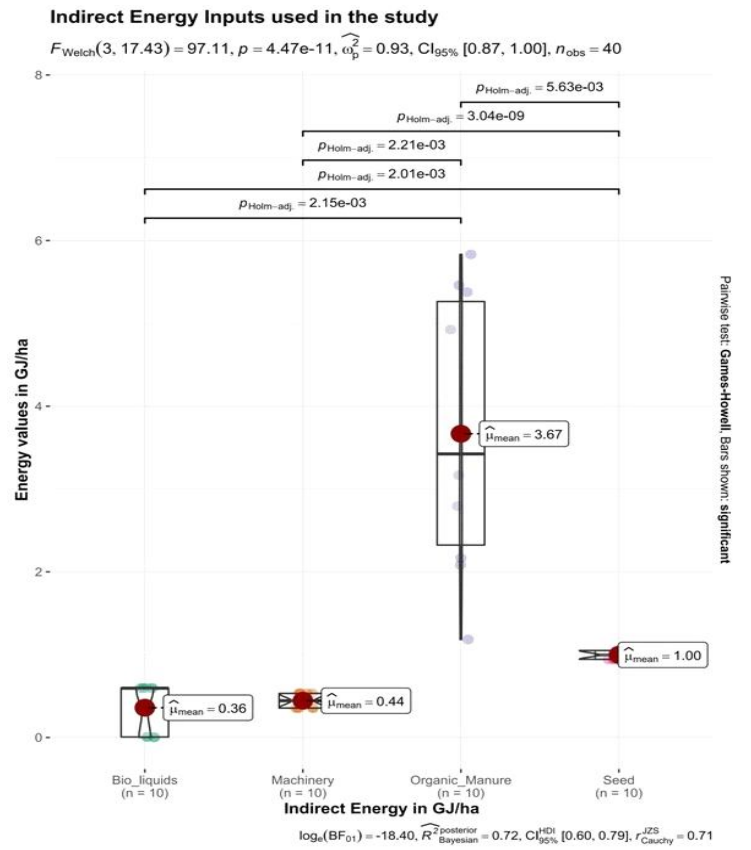


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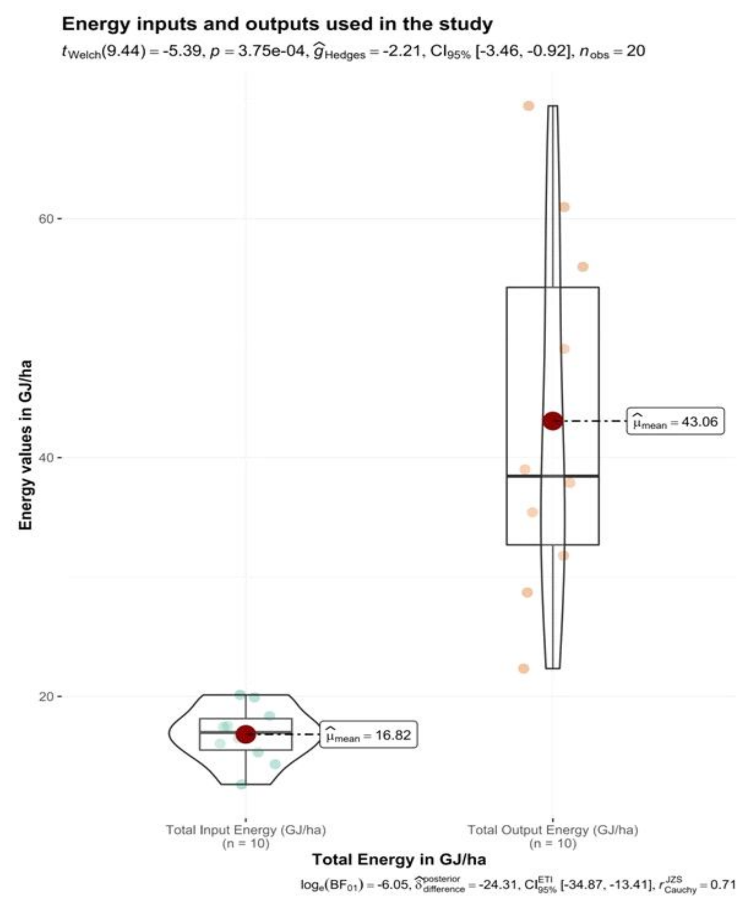
Fig 2: Indirect energy inputs used in the study (GJ/ha).

Table 5: Technical (TE), Allocative (AE) and cost efficiency (CE) of the different organic nutrient managements in cotton (DEAP software).

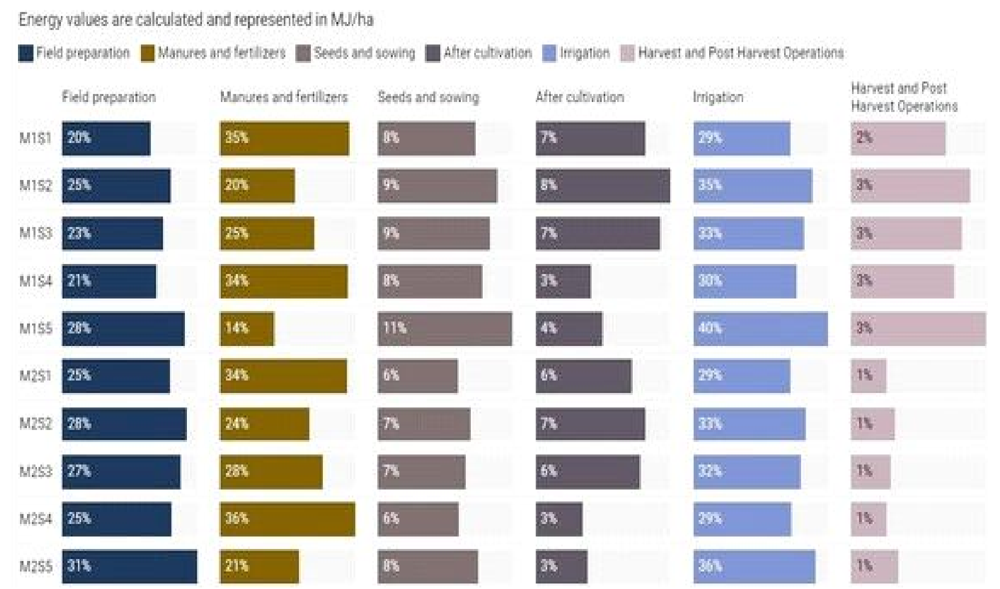
Treatments	CRS TE	VRS TE	SE	AE	CE
M_1S_1	0.926	1	0.926	0.686	0.686
M_1S_2	1	1	1	1	1
M_1S_3	0.853	1	0.853	0.861	0.861
M_1S_4	1	1	1	0.796	0.796
M_1S_5	1	1	1	1	1
M_2S_1	0.971	0.999	0.972	0.743	0.742
M_2S_2	1	1	1	1	1
M_2S_3	0.815	0.991	0.822	0.794	0.784
M_2S_4	1	1	1	0.735	0.735
M_2S_5	1	1	1	0.945	0.945
Mean	0.956	0.999	0.957	0.847	0.846

CRS TE= Technical efficiency from constant return scale DEA, VRS TE= Technical efficiency from variable return scale DEA.



The box-violin plots are created using R studio programming software v 4.2.0. p-value <0.005 represent the significance.

Fig 3: Total energy inputs and outputs used in the study (GJ/ha).



The split bar plots are created using datawrapper software.

Fig 4: Operation-wise energy budgeting of organic nutrient management practices in organic cotton.

Table 6: Frequency distribution of technical, scale, allocative and cost efficiency.

Efficiency levels (%)	TE_{CRS}		TE_{VRS}		SE		AE		CE	
	No. of. ONM practices	Total ONM practices (%)	No. of. ONM practices	Total ONM practices (%)	No. of. ONM practices	Total ONM practices (%)	No. of. ONM practices	Total ONM practices (%)	No. of. ONM practices	Total ONM practices (%)
1.00	6	60	8	80	6	60	2	20	2	20
0.90 to <1.00	2	20	2	20	2	20	1	10	2	20
0.80 to <0.90	2	20	0	0	2	20	1	10	1	10
<0.80	0	0	0	0	0	0	6	60	5	50
Mean		0.956		0.999		0.957		0.847		0.845
Maximum		1.000		1.000		1.000		1.000		1.000
Minimum		0.815		0.991		0.822		0.686		0.686
SD		0.069		0.003		0.067		0.113		0.114

Table 6, assuming VRS, only 20% (2 ONM practices) of cotton fields were operating at 90 to 100% efficiency levels.

CONCLUSION

The present study was aimed to work out energy budgeting and efficiency analysis of different organic nutrient management practices of organic cotton and to explain variations in energy usage and efficiency levels among the ONM practices. This study uses the data acquired from the field experiment conducted from June 2022 to February 2023. The direct and indirect energy used in different ONM practices were computed and used as input in energy budgeting and efficiency analysis. Energy coefficients were computed from energy equivalents and that has been used as inputs to generate efficiency coefficients by using an input oriented DEA approach. Data shows that mean technical, allocative, scale and cost efficiencies were 99, 84.7, 95.7 and 84.5 per cent, respectively. Efficiency scores imply the nutrient management practices are technically efficient, but there is a scope of improving their allocative and cost efficiency levels, by 15.3% and 15.5%, respectively. As a result, cotton producers in the research region must be informed about the effects of the inputs utilised in cotton cultivation. Education and awareness can help to encourage the proper input selection and utilization.

From, this study, organic cotton growers of this study area are recommended to follow the double green manuring followed by cotton (CO 17 variety) and application of well decomposed poultry manure and foliar application of fermented fish extract at 5% concentration at 25 and 35 DAS to achieve maximum returns in winter irrigated cotton.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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