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Energy Budgeting of Different Cropping Sequences in the Indian Upper Gangetic Plains

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ABSTRACT

Background: This study is meant to examine the energy requirement and energy input- output of different cropping sequences. The crucial objective to conduct experiment to understand energy efficiency using inputs and outputs which were disbursed in cropping sequences. Hence, it is need of the hour to identify the most remunerative and cost effective cropping sequence with high energy efficient for UGP of India.

Methods: This study was carried out at the research farm of ICAR-Indian Institute of Farming Systems Research, Modipuram, during 2017-2021. The divergent cropping sequences *viz.* sugarcane-ratoon-wheat (CS_1); rice-wheat-dhaincha (CS_2); pigeonpea + maize-chickpea-okra (CS_3); maize-berseem-black gram (CS_4); sorghum-mustard-green gram (CS_5) and Napier+cowpea/berseem (CS_6) were compared in reference to curtail higher energy inputs through selected alternate cropping sequences. The obtained energy values were calculated by multiplying the amount of inputs and outputs by using energy conversion factors.

Result: Maximum inputs energy consumed by sugarcane crop alone (33.14×10^3 MJ ha^{-1}). Results shown that irrigation, seed, fertilizers and diesel required higher energy for the completion of cultural operations. However, higher inputs energy was used in irrigation followed by seed and fertilizers, respectively. In regard to per cent energy intake through inputs, the highest energy spent was for irrigation (35.30 MJ ha^{-1}) and fertilizer (23.80 MJ ha^{-1}).The wheat equivalent yield was higher in sugarcane-ratoon-wheat (125.58 t ha^{-1}). Maximum output energy was with above system (596.70×10^3 MJ ha^{-1}). Highest net energy returns was counted with sugarcane-ratoon-wheat (549.37×10^3 MJ ha^{-1}), energy ratio (12.60) and energy profitability (11.60). Indeed, energy efficiency was highest in same system (1657.50) followed by maize-berseem-black gram (1421.96).

Key words: Cropping sequence, Energy input, Energy output, Energy profitability, Net energy return, Wheat equivalent yield.

INTRODUCTION

Energy inputs are crucial for the crop production and increased use of fossil fuel energy resources has become important to both developed and developing countries. In India, energy use in agriculture has been increasing since the green revolution in the late sixties with increasing use of high yielding varieties, synthetic fertilizers, agro-chemicals, herbicides, machinery as well as diesel and electricity in farm operations leading to higher productivity. The era of low priced energy is now ending and energy conservation has become more vital because rising cost of energy sources. Therefore, relation between crop production and energy use is very close. The energy inputs are inevitable features for fruitful crop growing in Indo-Gangetic Plains because high energy requires crops are being cultivated in the area such as sugarcane, rice, wheat, potato and oilseed crops. The availability of power on the farm is required more and more for enhancing crop productivity and profitability. Energy is used in every form of input *viz.* labour, seed, fertilizer, irrigation and insecticides for the plant protection, machinery use for various operations and farm machinery is directly linked with technological progress made in India. In the present years, a worldwide energy crisis prevailing due to fuel shortage and high prices of petroleum based products. The energy

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crisis country like India had an adverse effects on the economy growth. Among the field crops, legumes and oilseed, involves have less energy requirement than other crops. Looking at the crops like rice, wheat, maize and sugarcane required higher energy inputs, mainly for their higher demands of irrigation and fertilizers coupled with cultural operations (Pathak *et al*., 2022). The production of crops in diversified manner with advanced yield targets cannot be achieved without use of high energy inputs. The increase in crop productivity also needed additional supply of mechanical power along with adequate supply of chemical energy (Devasenapathy *et al*., 2009). Hence, increase additional cropping intensity over existing required higher supply of energy for the inputs like labour, seed, fertilizers, irrigation and farm implements for tillage, harvest and threshing (Verma, 2006). The production factors have encouraged an increase in energy inputs to maximize the yields and minimize labor-intensive operations (Shah and Wu, 2019). Hence, there is an urgent need to sustain productivity of various crops in India through inclusion of remunerative crops which are highly energy efficient. This can be possible by added of customary energy input *i.e*. human labour with substantial investments in farm machemary, irrigation, equipment's, fertilizers, soil and water conservation practices *etc*. These inputs and methods represent various energies that need to be evaluated so as to ascertain their effectiveness and to know how to conserve them (Walia *et al*., 2014). Energy computing is necessary for efficient management of scarce resources for improved crop production in Indian scenario because faster decline in natural resources and climate change are the major concerned. It would be better to ascertain a high energy efficient output system with low energy input requirement and that would be an economically viable and livelihood for the farmers of Uttar Pradesh in India.

MATERIALS AND METHODS

The purpose of this study was to determine the amount of energy ingesting *i.e*. the amount of inputs and outputs used in different cropping sequences to make an economic analysis at ICAR-Indian Institute of Farming Systems Research, Modipuram, Uttar Pradesh for a period of 4 consecutive years (2017-18 to 2020-21). The experiment site (29°43′N latitude and 77°23′E longitude at an elevation of 237 m above mean sea level) is classified as semi-arid sub-tropical with monsoonal climate and sandy loam soil classified as Typicusforthents. During the experimental period the site received total annual rainfalls of 730.3 mm, 976.7 mm, 824.3 mm and 897.5 mm in 37, 44, 42 and 44 rainy days, respectively. More than 80% of rainfall was received through the south-west monsoon. The mean annual minimum and maximum temperatures ranged between 18.1°C and 30.7°C (2017-18), 17.4°C and 30.5°C (2018-19), 17.0°C and 29.9°C (2019-20) and 16.9°C and 30.2°C (2020-21). While the humidity stands at 72.7%, 72.7%, 74.2% and 75.2% in respective years (Fig 1). The mean over a period of 4 years of sunshine hours were 6.3 and pan evaporation (mm) was higher (1575.45 mm) than normal annual rainfall. The total soil organic carbon (TSOC) was 0.89% (CHNS analyzer). Available N (176.6 kg/ha) was estimated by alkaline permanganate ($KMnO_4$) method. Similarly, available soil P (29.3 kg/ha) was analyzed by (Jackson's, 1973) method and available soil K (194.7 kg/ha) was estimated by NH_4OAc method.

Energy inputs estimations were based on the human labour requirement, use of different types of machinery and quantity of materials, energy calculation was computed though using of different input and output energy equivalents.

Manual energy (*Em*) was determined through using of following formula (Gopalan *et al*., 1987).

$$Em = 1.96\ Nm\ Tm\ MJ$$

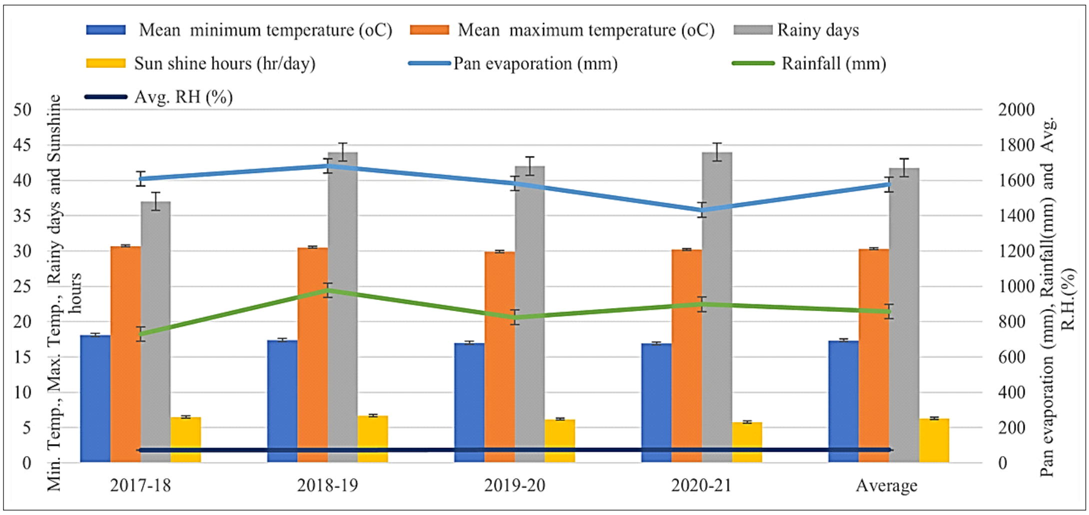

Fig 1: Annual average meteorological data recorded at Agromet Observatory, ICAR-IIFSR, Modipuram.

Where:
Nm= Number of labour spent on a farm activity.
Tm= Useful time spent by a labour on a farm activity. h.

The energy coefficients used in the calculations are presented in Table 1. The total manual labour was recorded in each operation with working hours, which was converted

Table 1: Equivalent coefficient for various inputs sources of energy used for energy calculation under different cropping sequences.

Inputs	Unit	Energy equivalent (MJ unit^{-1})	References
Human labour			
Human labour (Male)	h	1.96	Ghose *et al.* (2021)
Human labour (Female)	h	1.57	Ghose *et al.* (2021)
Harvesting	h	1.96	Singh and Mittal (1992)
Spraying	h	1.96	Ram and Verma (2015)
Transportation	kg	1.08	Pimentel and Burgess (1980)
Water	m^3	1.02	Tuti *et al.* (2012)
Cultural practices	h	1.96	Singh and Mittal (1992)
Machinery			
Sprayer	h	0.50	Nassiri and Singh (2009)
Tractor	h	64.80	Pathak *et al.* (2022)
Sickle	h	0.83	Nassiri and Singh (2009)
Farm machinery	kg	62.70	Tuti *et al.* (2012)
Electricity	KWH	11.93	Ozkan *et al.* (2004)
Electric motor (Two horsepower)	kg	64.80	Devasenapathy *et al.* (2009)
Machinery (All kind)	kg	68.40	Singh and Mittal (1992)
Diesel	l	56.31	Canakci and Akinci *et al.* (2003)
Chemical fertilizers			
Nitrogen (N)	kg	60.60	Toader and Gheorghe (2014)
Phosphorus (P_2O_5)	kg	11.10	Toader and Gheorghe (2014)
Potassium (K_2O)	kg	6.70	Devasenapathy *et al.* (2009)
Zinc sulphate ($ZnSo_4$)	kg	20.90	Singh and Mittal (1992)
Plant protection			
Fungicide	kg	97	West and Marland (2002)
Herbicides	kg	288	Pimentel and Burgess (1980)
Insecticide	kg	237	West and Marland (2002)
Organic fertilizers			
Manure/FYM	kg	0.30	Tuti *et al.* (2012)
Vermicompost	kg	0.50	Ram and Verma (2015)
Biofertilizers	kg	2.98	Mihov *et al.* (2012)
Sugarcane seed	kg	2.00	Singh and Mittal (1992)
Seed cutting and stalk (sugarcane)	kg	1.20	Ricaud (1980)
Wheat seed	kg	14.70	Singh and Mittal (1992)
Paddy seed	kg	14.70	Singh and Mittal (1992)
Dhaincha seed	kg	14.70	Mittal *et al.* (1985)
Pigeonpea seed	kg	14.70	Singh *et al.* (1997)
Maize seed	kg	14.70	Singh and Mittal (1992)
Chickpea seed	kg	25.00	Thyagaraj (2012)
Lady finger (seed)	kg	25.60	Roy *et al.* (2015)
Berseem seed	kg	10.00	Singh and Mittal (1992)
Black gram seed	kg	13.96	Gopalan *et al.* (2006)
Sorghum seed	kg	12.60	Mittal *et al.* (1985)
Mustard seed	kg	25.00	Mittal *etal.* (1985)
Green gram seed	kg	14.70	Singh *et al.* (1997)
Napier seed (cuttings)	kg	2.00	Singh and Mittal (1992)
Cowpea seed	kg	14.70	Singh and Mittal (1992)

in man-hour. All other factors affecting manual energy were neglected.

Mechanical energy input was evaluated by quantifying the amount of diesel fuel consumed during the tillage, sowing, threshing and winnowing as prescribed methodology. The total time spent was also recorded during irrigation. Hence, for every farm operation, the diesel fuel energy input was determined by:

$$Ef = 56.31DMJ$$

Where:

56.31= Unit energy value of diesel, MJ^{-1}.

D= Amount of diesel consumed, L.

Energy value for various input and output use in the experiments is given Table 1. The total energy input for a given cropping system was calculated by adding the energy requirement for human labour, insecticides, seeds, irrigation, farm yard manure (FYM), Vermicompost (VC), fertilizers and diesel, used in the individual cropping sequence. The energy output was calculated by accumulating the main products and by products produced from the different crops in cropping sequences. Subtracting input energy from output energy derived the net returns of energy. The output: input ratio was worked out by dividing the total energy used for raising the crop in the unit area (Table 2). The energy input and output were computed as Mega Joule (MJ) by using different formulae. The energy efficiency (EE) and specific energy (SE) were worked out as per Dazhong and Pimental (1984).

RESULTS AND DISCUSSION

Energy input consumed in the cropping sequences

Details of energy equivalent (conversion coefficient) of all inputs used in the different cropping sequences are shown in Table 3. The relative amount of energy inputs in all cropping sequences involved 12.28% to 21.01 % for human labour (HL), 11.17% to 22.71% energy incurred in tractor/ diesel consumption, energy consumed in chemical fertilizers ranged between from13.86% to 21.74%, input energy in the form of pesticides used from 4.86% to 32.18%, energy inputs used in supplied of irrigations were diverse from 7.71% to 27.87% and it depends up on the water requirement of each crop and growing duration. Energy

Table 2: Equivalent coefficient for various outputs for energy calculation under different cropping sequences.

Outputs	Unit	Energy equivalent ($MJ\ unit^{-1}$)	References
Sugarcane	kg (harvested mass)	5.30	Mittal *et al.* (1985)
Sugarcane leaves and tops	kg (dry mass)	15.10	Smithers (2014)
Wheat grain	kg	14.70	Singh and Mittal (1992)
Wheat straw	kg	12.50	Nisar *et al.* (2021)
Paddy grain	kg	14.70	Jackson *et al.* (2010)
Paddy straw	kg	12.50	Singh and Mitta l(1992)
Dhaincha dry matter	kg	18.00	Mittal *et al.* (1985)
Pigeonpea seed	kg	14.70	Singh *et al.* (1997)
Fuel wood (pigeon pea)	kg	12.50	Suri *et al.* (2016)
Chickpea seed	kg	25.00	Thyagaraj (2012)
Chickpea by product	kg	12.50	Mandal *et al.* (2002)
Sorghum by product (dry matter basis)	kg	12.50	Fisher *et al.* (2007)
Sorghum (silage) fresh	kg	3.10	Bazaluk *et al.* (2021)
Lady finger (fruit)	kg	1.60	Mittal *et al.* (1985)
Lady finger dry biomass	kg	18.00	Devasenapathy *et al.* (2008)
Maize grain	kg	14.70	Devasenapathy *et al.* (2009)
Maize straw	kg	12.50	Nisar *et al.* (2021)
Berseem green fodder	kg	2.30	Mittal *et al.* (1985)
Black gram seed	kg	13.96	Gopalan *et al.* (2006)
Black gram straw	kg	12.5	Devasenapathy *et al.* (2009)
Sorghum(fodder)	Kg (dry mass)	18.0	Mittal *et al.* (1985)
Sorghum (silage) fresh	kg	3.10	Bazaluk *et al.* (2021)
Mustard seed	kg	25.00	Mittal *et al.* (1985)
Mustard straw	kg	12.50	Mittal *et al.* (1985)
Green gram seed	kg	14.70	Singh *et al.* (1997)
Green gram straw	kg	11.23	Soni *et al.* (2013)
Napier	kg (dry mass)	18.00	Mittal *et al.* (1985)
Green fodder (Cowpea)	kg (fresh mass)	2.30	Lal *et al.* (2003)

consumed for using of farm yard manure (FYM) to grow crops founded at 8.68% to 26.08%, VC (Vermicompost) supplied in the crop production required energy value to the tune from 5.26% to 26.31% under various cropping sequences. The crucial energy input like seed was used in crop production required highest in sugarcane-ratoon-wheat sequence from 5.83% to 54.65% in sorghum-mustard- green gram when compared with other cropping sequences. Ozkan *et al*. (2007) similarly found that inputs energy differed with the cropping sequences due to varying energy coefficients, The highest was being in sugarcane-ratoon-wheat system (47.33×10^3 MJ ha^{-1}) and wellbeing ahead by rice-wheat- dhaincha (R-W-D) system (39.52×10^3 MJ ha^{-1}) and the lowest in Napier+cowpea/berseem cropping sequence (29.05×10^3 MJ ha^{-1}). Energy consumption for irrigation (71.199 MJ ha^{-1}), fertilizer (47.992 MJ ha^{-1}), tractor/diesel (28.115 MJ ha^{-1}) and seed (20.944 MJ ha^{-1}) were the prime factors responsible for putting the crops and cropping sequences in the highest position in terms of total energy requirement for the production main and byproducts.

System wise input energy requirement

Energy inputs consumed in different cropping sequences as reported in Table 4. The computation of energy linked inputs which were used for the crop production revealed that the total energy inputs were highest in case of sugarcane-ratoon-wheat (S-R-W) system because of this cropping pattern have the maximum demand of all inputs (47769 MJ ha^{-1} year^{-1}) when comparison was made with other cropping sequences and the next cropping sequence which needed bulk energy inputs was rice-wheat-dhaincha (R-W-D) *i.e*. (39522 MJ ha^{-1} year^{-1}). Despite this, least input energy was spent in maize-berseem-black gram (25785 MJ ha^{-1} year^{-1}). The reason for the declined in inputs use energy was selection of crops like berseem and black gram as compared to high demanding energy inputs crops like sugarcane, rice, wheat and maize. Among the energy inputs, irrigation, fertilizers and tractor/diesel are having primary importance for output production. The total input energy was highest spent towards irrigations (35.43%), fertilizers (23.89%), tractor/diesel (14.00%) and seed (10.42%), respectively. In fact, irrigation input energy is required highest for the crop production because some crops have been involved in the sequences they have high demands of irrigation than others. The cost of energy input of different crops and cropping sequences can be reduced by the selection of apposite sequences. The total annual energy inputs for the cropping sequences ranged from about 47769 MJ ha^{-1} year^{-1} under sugarcane-ratoon- wheat (S-R-W) to 25785 MJ ha^{-1} year^{-1} in maize- berseem- black gram (M-B-BG). It is generally, pragmatic that short span crops like legumes and oilseeds have lowest demand of energy inputs than other crops *viz*. sugarcane, rice, maize, wheat *etc*. Tuti *et al*. (2012), described that wheat required more energy than other crops.

Table 3: Mean (of four years) inputs requirements of the individual crops grown during 2017-18 and 2020-21.

Cropping system	Human labour (h)	Tractor (h) and diesel (l)	Fertilizers (kg)	Pesticide (l)	Irrigation (m^3)	Farm yard manure (kg)	VC (kg)	Seed (kg)	Total input energy ($\times10^3$ MJ ha^{-1})
Sugarcane-ratoon-wheat									
Sugarcane	0.947	2.804	6.055	0.306	11.280	1.500	0.375	9.877	33.14
Wheat	0.595	2.104	4.381	0.102	3.570	1.500	0.375	1.570	14.19
Rice-wheat-dhaincha									
Rice	0.893	1.166	3.502	0.204	13.260	-	-	1.445	20.47
Wheat	0.478	1.264	4.208	0.306	5.130	1.500	0.375	1.570	14.83
Dhaincha	0.089	0.896	1.545	-	1.457	-	-	0.234	4.22
Pigeonpea+maize-chickpea-okra									
Pigeonpea+maize	0.392	2.104	1.790	0.051	3.315	0.750	0.375	0.294	9.07
Chickpea	0.392	1.309	2.006	0.051	1.632	0.750	0.625	0.960	7.72
Okra	0.047	2.974	3.530	0.600	3.825	1.500	0.625	0.512	13.61
Maize-berseem-black gram									
Maize	0.549	2.127	4.503	0.204	1.785	0.750	0.625	0.360	10.90
Berseem	0.580	1.515	1.073	0.002	1.028	1.500	0.625	0.750	16.32
Black gram	0.533	0.791	1.078	0.255	2.678	1.500	0.625	0.349	7.80
Sorghum-mustard-green gram									
Sorghum	0.392	1.734	2.780	0.004	4.250	1.500	0.625	0.756	12.04
Mustard	0.298	2.449	3.146	0.102	1.786	1.500	0.625	0.100	10.00
Green gram	0.219	1.735	0.873	-	2.678	1.500	0.625	0.367	7.99
Napier+cowpea/berseem									
Napier+cowpea/berseem	0.941	3.143	7.522	-	13.525	1.500	0.625	1.800	29.05

Wheat equivalent yield

The pooled analysis data indicated that annual wheat equivalent yield of sugarcane-ratoon-wheat (S-R-W) sequence was significantly higher than rest of the crop rotations (Table 5). Since the sugarcane have the higher yield potential and market value than other crops which were included in different cropping sequences. The divergent crops were grown among the different cropping sequences, so that the main and byproducts yields of all crops were converted into wheat equivalent yield (WEY t ha^{-1}) on the basis of prevailing market price of each commodity. Similar results were also reported by (Anishetra and Kalghatagi (2021) and Sujathamma and Nedunchezhiyan (2024) in cropping sequences. The wheat grain prices were comparable parameter with other farm produces and their market worth in order to take the wheat values equivalent to other crops produces at par because productivity and market values were different among themselves. The wheat equivalent yield (WEY t/ha) was highest with sugarcane-ratoon-wheat cropping sequence (125.58 t ha^{-1}year^{-1}) followed by Pigeonpea+ maize- chickpea-okra (29.02 t ha^{-1} year^{-1}) and minimum wheat equivalent yield (WEY) was estimated with Napier + cowpea/berseem (2.47 t ha^{-1} year^{-1}). This might be due to under this cropping sequence consisted mainly by fodder crops rather than valuable crops. The equivalent wheat yield is governed by quantity of produce and its prevailing price and combined effect of these two ultimately led to maximum equivalent yield. This finding corroborates the observations of (Ozkan *et al.*, 2007).

Energy outputs of cropping sequences

The total output energy was highest in sugarcane-ratoon-wheat cropping sequence (597.70 GJ ha^{-1} year^{-1}) followed by rice-wheat-dhaincha (463.44 GJ ha^{-1} year^{-1}), maize-berseem-black gram (369.71 GJ ha^{-1} year^{-1}) and Napier + berseem/cowpea (333.50 GJ/ha) as detailed in Fig 2. The lowest energy output was shared by sorghum - mustard-green gram (319.53 GJ ha^{-1} year^{-1}) and pigeonpea+ maize-chickpea-okra (280.09 GJ ha^{-1} year^{-1}). However, main output energy from the different cropping sequences have paid more than their byproducts outcome energy. The perceptible output energy was produced where sugarcane, rice, wheat, maize and mustard crops were composed with other crops in the cropping sequences. The total energy production from the different crops and cropping systems varied from

Table 4: System wise input energy and total energy consumed in the different cropping sequences (MJ ha^{-1}).

Cropping sequence	Human energy (MJ ha^{-1})	Tractor/Diesel energy (MJ ha^{-1})	Seed energy (MJ ha^{-1})	Fertilizer energy (MJ ha^{-1})	Pesticides energy (MJ ha^{-1})	Irrigation energy (MJ ha^{-1})	FYM energy (MJ ha^{-1})	VC (MJ ha^{-1})	Total energy consumed (MJ ha^{-1})
S-R-W	1542	4908	11447	10436	408	14778	3500	750	47769
R-W-D	1460	3326	3249	9255	510	19847	1500	375	39522
P+M-C-O	831	6387	1766	7326	702	8772	3000	1625	30409
M-B-BG	1662	4433	1459	6654	461	5491	3750	1875	25785
S-M-GG	909	5918	1223	6799	106	8714	3625	1875	29169
N+C+B	941	3143	1800	7522	-	13525	625	625	28172

Note: S-R-W (Sugarcane-ratoon-wheat); R-W-D (Rice-wheat-dhaincha); P+M-C-O (Pigeonpea + maize-chickpea-okra); M-B-BG (Maize- berseem-black gram); S-M-GG (Sorghum-mustard- green gram); N+C+B (Napier+ cowpea/berseem).

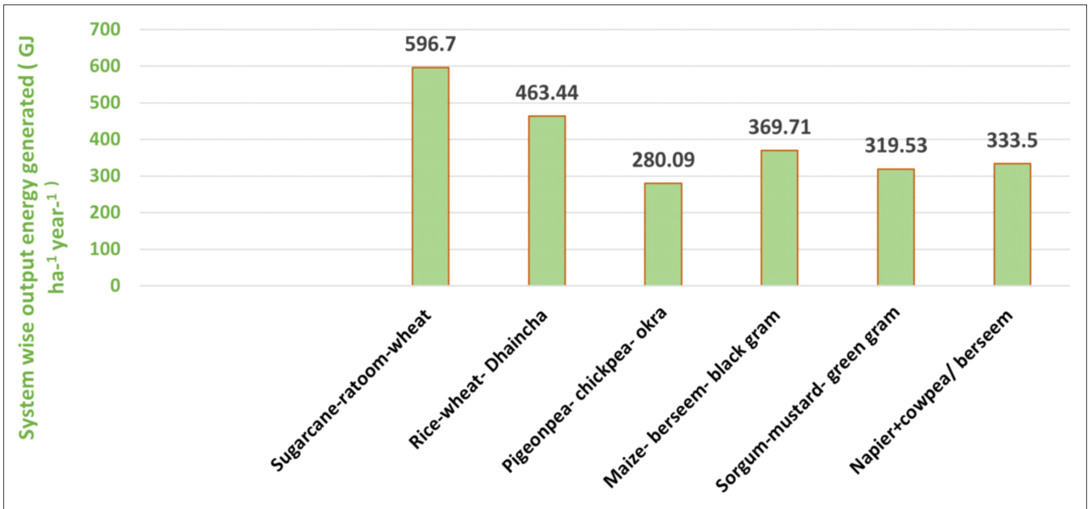

Fig 2: Cropping systems adopted in upper gangetic plains of India.

Table 5: Details of outputs as main and by-products and wheat equivalent yield and energy returns from the different cropping sequences in western upper gangetic plains of India.

Cropping sequences	Main product (kg)				Byproducts (kg)				WEY (t ha^{-1})	Total energy equivalent ($\times 10^3$ MJ ha^{-1} year^{-1})
	Kharif	*Rabi*	*Summer*	Energy equivalent ($\times 10^3$ MJ ha^{-1} year^{-1})	*Kharif*	*Rabi*	*Summer*	Energy equivalent ($\times 10^3$ MJ ha^{-1} year^{-1})		
Sugarcane-ratoon-wheat										
Sugarcane	-	-	760000	402.80	-	-	11400	34.42	118.95	437.23
Wheat	-	4944	-	72.68		6944	-	86.80	6.63	159.47
Rice-wheat-dhaincha										
Rice	5667	-	-	81.83	7667	-	-	95.83	7.05	177.66
Wheat	-	4556	-	66.97	-	5639	-	70.49	6.18	137.46
Dhaincha	-	-	2916	52.49	-	-	-		2.16	52.49
Pigeonpea-chickpea-okra										
Pigeonpea	1389	-	-	20.42	8544	-		106.80	5.38	127.22
Chickpea	-	2500	-	62.50		3222	-	40.27	6.65	102.77
Okra	-	-	12667	20.26	-		1658	29.84	16.99	50.10
Maize-berseem-black gram										
Maize	7028	-		103.31	5961			74.51	7.73	177.82
Berseem	-	68000	-	156.40	-	-			9.07	156.40
Black gram	-	-	889	12.41	1847	-		23.08	2.96	35.49
Sorghum-mustard-green gram										
Sorghum	48000	-	-	148.80	-	-			4.26	148.80
Mustard		3089	-	77.22	-	4161	-	52.01	7.73	129.23
Green gram	-	-	867	12.74	-	-	2561	28.76	4.02	41.50
Napier+cowpea/berseem										
Napier+ cowpea/berseem	6208	5760	6560	333.50	-	-	-		2.47	333.50
								SEm±	16.28	
								CD (*P*=0.05)	39.88	

Table 6: System wise total inputs energy, total outputs energy and net energy return of different cropping sequences (Data pooled over 4 years).

Cropping sequence	System input energy ($\times 10^3$ MJ ha^{-1} $year^{-1}$)	System output energy ($\times 10^3$ MJ ha^{-1} $year^{-1}$)	System net energy returns ($\times 10^3$ MJ ha^{-1} $year^{-1}$)	Energy ratio ($\times$103 MJ ha^{-1} $year^{-1}$)	Energy profitability	Energy output efficiency
CS1: Sugarcane-ratoon -wheat	47.33	596.70	549.37	12.60	11.60	1657.50
CS2: Rice-wheat-dhaincha	39.52	367.61	328.09	9.30	8.30	1225.36
CS3: Pigeonpea+ maize-chickpea -ladyfinger (okra)	30.32	280.09	249.77	9.23	8.23	856.54
CS4: Maize-berseem-black gram	35.04	369.71	334.67	10.55	9.55	1421.96
CS5: Sorghum-mustard-green gram	30.04	319.53	289.49	10.63	9.63	1125.10
CS6: Napier+cowpea/berseem	29.05	333.50	304.45	11.48	10.48	913.69

25.25% to 11.85%. However, maximum total energy output was contributed by the sugarcane-ratoon- wheat sequence (4 years) as compared to other cropping sequences. The main season of production of high energy output from this system was due to greater potential of sugarcane alone than remaining crops which were included in the various configurations.

Energy input-output relationship

The total inputs and outputs energy of different cropping sequences were varied depending up on the crops involved and the practices used (Table 6). However, resource inputs energy was disbursed highest in sugarcane- ratoon- wheat (47.33×10^3 MJ ha^{-1} $year^{-1}$) as compared to rest of the systems. The minimum input energy was used in Napier+cowpea/berseem (29.05×10^3 MJ ha^{-1} $year^{-1}$) sequence because demands of the chemical fertilizers, irrigation, tractor/diesel and seed were smaller than other cropping sequences. Apart from these, there were no use of insecticides and pesticides in case of fodder crops leading to decline in input energy consumption. Besides, during *Kharif* season requirement of irrigation was meager and nutrients requirement of Napier hybrid bajra was met through intercropping of legumes (cowpea and berseem) concurrently in *Kharif* and *rabi* seasons. Similarly, output energy was generated highly in sugarcane-ratoon-wheat cropping sequence and followed by maize- berseem- black gram (369.71×10^3 MJ ha^{-1} $year^{-1}$), rice-wheat-dhaincha (367.61×10^3 MJ ha^{-1} $year^{-1}$) and Napier + cowpea/ berseem (333.50×10^3 MJ ha^{-1} $year^{-1}$). The lowest output energy was given by Pigeonpea + maize-chickpea-ladyfinger (okra) crop sequence (280.09×10^3 MJ ha^{-1} $year^{-1}$). The net energy was highest in sugarcane-ratoon-wheat (549.37×10^3 MJ ha^{-1} $year^{-1}$) and thereafter in maize- berseem- black gram (334.67×10^3 MJ ha^{-1} $year^{-1}$) and rice-wheat-dhaincha (328.09×10^3 MJ ha^{-1} $year^{-1}$). The system net energy was minimum under pigeonpea+maize-chickpea-okra (249.77×10^3 MJ ha^{-1} $year^{-1}$). This might be due to these crops are highly exhausted towards required inputs and lesser responsive to output energy led to less net energy in the system. The output energy was declined to the tune of 61.39%, 62.31 and 78.92% with maize-berseem- black gram, rice-wheat- dhaincha and Napier + cowpea/ berseem cropping sequences over to sugarcane-ratoon-wheat. Similarly, system net energy returns was declined in the tune of 64.15%, 67.44%, 80.44%, 89.77% and 119.95% with maize-berseem- black gram, rice- wheat- dhaincha, Napier + cowpea/berseem, sorghums-mustard- green gram and pigeonpea+maize-chickpea-okra cropping sequences over sugarcane-ratoon-wheat system. Similar results were also reported by (Afzalinia and Abdolhamid 2020) and (Venkat *et al*., 2024). The output- input ratio was highest in sugarcane-ratoon-wheat system (12.60) and closely followed by Napier + cowpea/ berseem (11.48), sorghums- mustard-green gram(10.68), maize- berseem-black gram (10.55) and lowest output-input ration was in pigeonpea + maize-chickpea-okra (8.23) and rice-wheat-dhaincha (8.30). The energy profitability was computed by system net energy returns and system input energy consumed. Numerically, maximum energy profitability was accounted with sugarcane-ratoon-wheat (11.60) followed by Napier+ cowpea/berseem (10.48) and sorghum-mustard- green gram (9.63). The least energy profitability was in pigeonpea+maize-chickpea-ladyfinger (8.23). The sugarcane-ratoon-wheat and maize-berseem- black gram systems were more efficient (1657.50 and 1421.96) than other cropping sequences due to high output energy and longest crop duration resulting in maximum times land occupied by the combination of crops and cropping sequences. Similar results were earlier reported by Negi *et al.* (2016) in various cropping sequences.

CONCLUSION

The outcomes revealed that energy consumption for irrigation (71.199 MJ ha^{-1}), fertilizer (47.992 MJ ha^{-1}), tractor/ diesel (28.115 MJ ha^{-1}) and seed (20.944 MJ ha^{-1}) were the prime factors responsible for putting the crops and cropping sequences in the highest position in terms of total energy requirement for the main and byproducts of sugarcane-ratoon- wheat cropping sequence. The crucial input like seed used in sugarcane required 54.65% energy alone as compared to other energy inputs. However, the highest input energy was used in sugarcane-ratoon-wheat cropping sequence (47.33×10^3 MJ ha^{-1}) followed by rice-wheat-dhaincha (39.52×10^3 MJ ha^{-1}). The total output energy (597.70 GJ ha^{-1} $year^{-1}$) and net energy returns (463.44 GJ ha^{-1} $year^{-1}$) were also highest with this sequence. Similarly, energy output efficiency (1657.50), output-input ratio (12.60) and wheat equivalent yield (125.58 t ha^{-1}) were highest under the same system. However, it would be better to ascertain a high energy efficient output system with low energy input requirement that could be an economically viable and livelihood for the farmers of Upper Gangetic Plains of India.

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Conflict of interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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