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A review on energy use and energy assessment in agriculture

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Abstract
Energy holds a key role in farming systems. Cultivation is based on the conversion of solar energy into biomass of interest (Pasteur *et al.,* 2020) [23]. The energy is equipped in all the equipments, operations, inputs and output or products of agriculture. Nowadays, the energy used in the agriculture is growing at a faster rate over the world. Currently, the agri-food chain accounts for 30 percent of the total energy used around the world. The optimization of land use, energy efficiency, end of the use of fossil energy sources and minimization of environmental impacts are very important for sustainable agricultural production (Mosavvi-Avval *et al.,* 2018) [41].

Efficient use of available resources in agricultural production is important to minimize energy use considering increase in the use of various energy inputs. Energy analysis can be done by using various energy indicators like Net energy, Energy ratio, Energy profitability, Energy productivity, Energy intensiveness. Concerning various inputs contribution to total energy input, chemical fertilizers were identified as the major contributors (73 and 47%) followed by FYM (20 and 22%) used to cultivate crops. Extensive use of indirect (82%) and non-renewable energy sources (69%) was noticed compared to direct (18%) and renewable energy sources (31%) (Manoj *et al.,* 2022) [36].

Keywords: Energy analysis, agriculture, net energy, energy ratio, energy profitability, energy productivity, energy intensiveness, fertilizers, fym, direct and indirect energy sources, renewable and non-renewable energy sources

Introduction

Energy, being the capacity to do work, is at heart of all human activities, especially those concerning the production of goods and services (Canakci and Akinci, 2006) [12]. Energy in all its forms is essential to humanity and is central to the improvement in people's quality of life (Contreras *et al.*, 2010) [13]. The continuous growth in energy demand, the inevitable decline in the availability of fossil fuels and the growing concerns about climate change have resulted to a number of activities from governments around the world to increase the production of energy from renewable sources (Quintero *et al.*, 2008) [53].

Energy plays a strategic role in the economic development of any country. There is increasing quest for energy and resource conservation agro-techniques in agriculture. Agriculture production nowadays causes more energy consumption due to mechanization in the form of use of fertilizers and chemicals in order to increase yield and machinery used to boost fieldwork productivity.

Analysis of energy is fundamental and essential for executing any well-defined energy management program. Agricultural productivity and profitability assessmemt in terms of energy budgeting is essential for efficient utilization and conserving natural resources. (1) The efficient energy use in agricultural systems are important for sustainability (2). Two of the most pressing sustainability issues are the depletion of fossil energy resources and the emission of atmospheric greenhouse gases like carbon dioxide like CO_2 to the atmosphere (Uhlin, 1998) [62]. Agriculture is both a sink and a source of atmospheric GHGs. Based on the operations and sources; energy use in plants varies according to different cropping systems. It was also found that energy use pattern also varies according to source of energy, climatic conditions, geographical locations, type of crop, etc.

Similarly, energy is also one of the most valueable inputs in agricultural production. There are various forms of energy such as mechanical (Farm machines, human labour, animal draft), chemical (Fertilizer, pesticides, herbicides), and electrical.

The processing and distribution should be significantly high to feed the expanding population and meet other social and economic goals. Sufficient availability of the right energy and its effective and efficient use are prerequisites for improved agricultural production. It has been realized that crop yields and food supplies are directly linked to energy (Stout, 1990) [61].

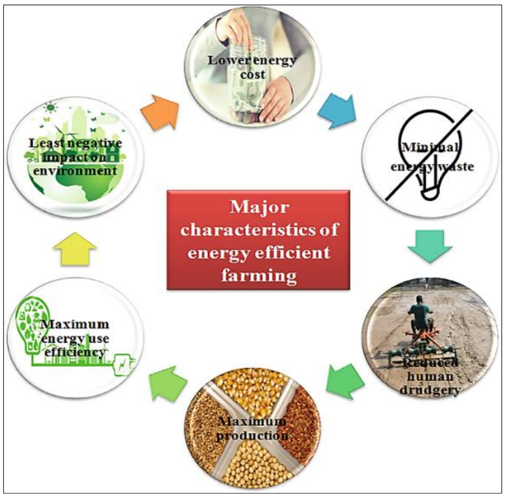


Fig 1: Major Characteristics of energy efficient farming

Agricultural productivity is closely linked with energy inputs. The measure of energy flow in crop production system provides a good indicator of the production of technological aspects of crop production systems in agriculture. Direct energy inputs to crop production are derived from energy sources like human, draught animals, engines, tractors, power tillers and electric motors etc., whereas indirect energy inputs are in the form of seeds, organic manures, fertilizers, pesticides and growth regulators, etc. (Patil *et al.*, 2022) [49].
Energy input-output relationships in cropping systems vary with the crops knitted in a sequence, type of soils, nature of tillage, operations, nature and amount of organic manures, chemical fertilizers, plant protection measures, yield level and biomass production (Devasenapathy *et al.*, 2008) [17]. Agriculture itself is a user and supplier of energy in the form of bio-energy (Alam *et al.*, 2005) [1]. In all societies, these factors have encouraged an increase in energy input to maximize yields, minimize lbour-intensive practices, or both (Esengun *et al.*, 2007) [19].
The energy input referred to the both renewable and non-renewable energy. Renewable energy constituted manual, animal / bullock, seed, manure, etc, whereas non-renewable energy comprised chemical fertilizers (NPK), tractor, diesel, electricity, lubricants, machinery and agro-chemicals, etc. The total physical output referred to both the grain and by-product i.e. straw yield (Patil., 2022) [49].
Energy input-output relationships in cropping systems vary with the crops grown in a sequence, type of soils, type of tillage operations, nature and amount of organic manure and chemical fertilizers, plant protection measures, harvesting and threshing operations, yield levels, biomass production (Singh *et al.*, 1997) [59].

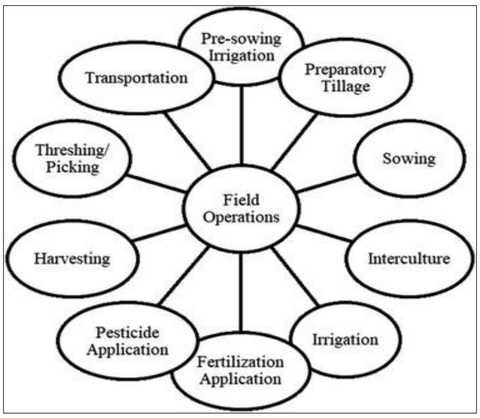
2.Energy analysis

The energy requirement for the cultivation of different crops was quantified by using various input components consumed and energy output produced from each cropping system (Manoj *et al.*, 2022) [36]. The energy inputs include both operational (direct) and non-operational (indirect) energy. Operational energy comprised manual work, fuel, machinery, etc. whereas non-operational energy consisted of seed, manure and chemical fertilizers (N and P) and agro-chemicals (Singh and Ahlawat, 2015) [54].
All the physical input and output components were converted into respective energy equivalents by multiplying them by their corresponding energy co-efficient (Manoj *et al.*, 2022) [36]. Mechanization have increased input energy with decreased operational costs. It was found that hoeing and weeding require more labour along with harvesting causing enhanced cost of operation.

Table 1: Types of energy and their sources

Types of energy	Energy sources
Direct energy	Humans, animals, petrol, diesel, electricity, and irrigation water from canals
Indirect energy	Seeds, farmyard manure, fertilizers, chemicals, and machinery
Renewable energy	Humans, animals, seeds, farmyard manure, and canal water
Non-renewable energy	Petrol, diesel, electricity, chemicals, fertilizers, and machinery
Commercial energy	Petrol, diesel, electricity, chemicals, fertilizers, seeds, and machinery

(*Source*: Kargwal *et al.*, 2022)



(**Source:** Kargwal *et al.*, 2022)

Fig 2: Different field operations in any crop production system

The amount of energy consumptions in any cropping system and its distribution throughout the system need to be optimized to cater the needs of increasing population at the global level in order to attain social objectives. The use of accurate energy source in both temporal and spatial context in modern-day agriculture is essential for management of natural resources in a proper way. In various countries cereals like paddy, wheat, sorghum, millet, barley and maize are used in human food as they are considered as a the primary source in a vegetarian diet. Also the accessibility of energy from cereal crop depends upon the type of grains consumed.

The major essential pulses consumed globally are beans, lentils, chickpea and soybean used as a staple food in rural and urban populations while it was used as a major cash crop in developed countries. Apart from this, oilseed crops like rapeseed, mustard, peanut, sunflower, cotton seed, palm kernel, canola, copra, etc. are mainly used as an oilseed crop consumed as oilseeds or crushed to get oil. The crops like cotton, tobacco, sugarcane, jute are grown mainly to sell in market and earn cash in return from market. Horticultural crops like tomatoes, banana, apple, watermelons forms an important part of human diet due to high proteinous and fibrous content and also high in vitamins and minerals.

2.1 Energy analysis indices

Energy analysis in any production system is carried out by using various energy indices like energy use efficiency, energy productivity, energy ratio, net energy, Specific energy and Mechanization index. The energy co-efficient are used in order to calculate energy indices.

Table 2: Energy equivalents (MJ unit^{-1}) of inputs and outputs of cropping system

Sr. No.	Input	Unit	Equivalent Energy (MJ Unit^{-1})
1	Diesel	liter	56.31
2	Machinery	hours	68.4
3	**Human Labor**		
	Male	hour	1.96
	Female	hour	1.57
4	**Seed**		
	Soybean	kg	14.7
	Chickpea	kg	25
	Maize	kg	14.7
	Safflower	kg	23.99
	Potato	kg	5.6
5	Chemicals (requiring dilution)	liter	237
6	Bio fertilizers	kg	2.98
7	Herbicide	liter	288
8.	FYM	kg	0.3
9	N	kg	60
10	P	kg	11.1
11	K	kg	6.7
12	Irrigation	Cubic meter	1.02

(*Source*: Ramanjeet Singh and Ahlawat, 2015) [54].

Table 3: Energy co-coefficients of various outputs obtained in a cropping system

Sr. No.	Output	Unit	Equivalent Energy (MJ Unit^{-1})
1	**Main products**		
	Soybean	Kg	14.7
	Chickpea	Kg	25
	Maize	Kg	14.7
	Safflower	G	23.99
	Potato	Kg	5.6
2.	**By-products**		
	Soybean	kg	10
	Chickpea	kg	10
	Maize	kg	17.18
	Safflower	kg	12.5
	Potato	kg	237

(*Source*: Ramanjeet Singh and Ahlawat, 2015) [54]

Various indices used in the assessment of energy have been explained as follows.

2.1.1 Energy efficiency

Energy efficiency (MJ ha^{-1}) is cultural energy utilized through inputs and energy produced as products are calculated and expresses as Mega Joules. In other words, energy use efficiency commonly called Energy Return on Energy Invest (EROI) is the ratio between output and input (Hall *et al.*, 2009, Hall, 2017) [22, 21].

Energy efficiency (EE) = Energy output/Energy input

2.1.2 Net energy (MJ/ha/year)

Net energy is defined as nothing but the difference between energy output and energy input of any cropping system.

Energy output (MJ ha^{-1}) - Energy input (MJ ha^{-1})

2.1.3 Energy productivity (kg MJ^{-1})
Energy productivity (kg MJ^{-1}) is defined as the total amount of harvested products divided by the total energy consumed by harvested products

Energy productivity (EP) = Output (grain+byproduct) (kg ha^{-1}) /Energy input (MJ ha^{-1})

2.1.4 Energy profitability
Net energy (MJ/ha/year)/ Total energy input (MJ/ha/year)

2.1.5 Energy intensiveness
Energy intensiveness is nothing but representing the cost of energy inputs consumed as a fraction of the total inputs (Zangeneh *et al.*, 2010, Choudhary *et al.*, 2017) [63, 14].

Energy input (MJ ha^{-1})/ Cost of cultivation (Rs ha^{-1})

2.1.6 Specific energy
Specific energy (MJ kg^{-1}) is the amount of energy spent to produce a unit of marketable product.

Specific energy (MJ kg^{-1}) = Energy input (MJ ha^{-1})/ Crop yield (kg ha^{-1})

2.1.7 Mechanization index
Mechanization index is defined as the percentage of machinery energy to the sum of human, animal and machinery energies. It is calculated by using following equation

Mechanization index (I_m)= Machine energy (EEM)/ Animal energy (EEA)+ Human energy (EEH)+ Machine energy (EEM).

2.1.8 Human Energy Profitability

Human Energy Profitability = Economic output (kg/ha)/labour energy (MJ/ha).

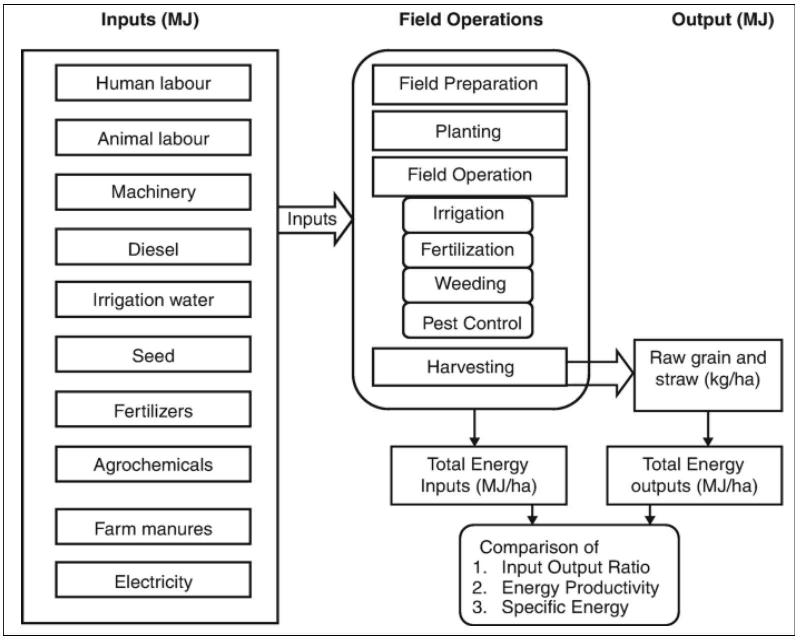


Fig 3: Various energy inputs and outputs in any crop production system.

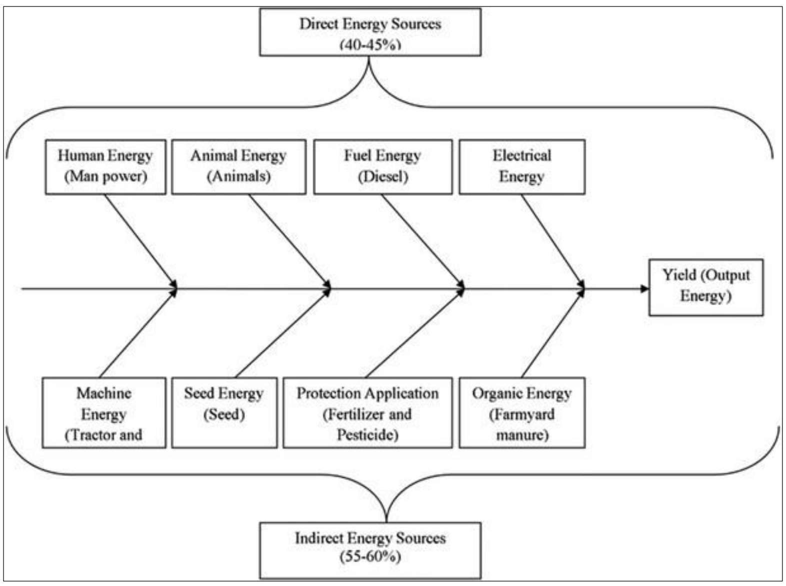


Fig 4: Share of direct and indirect energy sources in any crop production system (Kargwal *et al.*, 2022).

3. Energy use pattern in different crop production systems

Singh *et al*. (1993) [58] studied energy use in soybean-chickpea sequence and reported highest energy input in 100 -100 per cent RDF (9.75 MJ ha^{-1}). However, highest energy output was in 100 - 50 percent RDF (38646 MJ ha^{-1}) which was significantly higher than that of 100-100 per cent RDF (32222 MJ ha^{-1}). The highest energy use efficiency was obtained in treatment including 100-50 per cent RDF (4.66).

Legume based cropping system consumed less energy inputs than cereal based system and found more energy efficient. Also, it was observed that soybean-gram sequence was found most energy efficient followed by soybean-sunflower. The wheat cultivation either after soybean or sorghum showed least energy use efficiency. Energy productivity was found highest in soybean-gram cropping system followed by soybean-lentil.It was also stated by Billore *et al*. (1994) [10] that the soybean-gram sequence was the most energy efficient, productive and less energy intensive among all the sequence.

Bhatia (1995) reported from New Delhi that the total energy provided in terms of calories from all the crop sequences were at par, soybean-wheat-greengram gave higher (28.35 K X 10^6 calories ha^{-1}) energy followed by soybean-barley-green gram (28.66 X 10^6 calories ha^{-1}).

Franzlubbers and Francis (1995) conducted experiment on energy output:input ratio of maize and sorghum management systems in that are typical of eastern Nebraska, USA. Management variables were (1) Nitrogen fertilization, (2) Previous crop (cereal or legume), (3) Tillage (none or traditional), (4) herbicide (none, banded or broadcast), and (%) water (dryland, limited irrigation, or full irrigation). The energy output:input ratio ranged from 4.1+0.5 in fully irrigated, broadcast herbicide, traditional tillage systems with cereal as previous crop and no N fertilizer:11.6 +2.5 in dryland, broadcast herbicide. The energy output:input ratio decreased with the addition of N fertilizer in all management systems, except in fully irrigated, continous cereal systems. Management systems with legume as previous crop had a greater energy output: input ratio than those with cereal as previous crop.

Billore *et al.* (1996) [9] conducted experiment at Sehore to study the bio-energetic and economic feasibility of different cropping systems. The results revealed that the soybean based cropping sequences were more profitable than sorghum based sequences. The relatively higher land use and production efficiency were found in sorghum based sequences. However, soybean based cropping system were energy efficient, productive, remunerative and less energy intensive than sorghum based cropping system.

Kwatra *et al*. (2001) [32] evaluated the energetics of maize based cropping system in Uttar Pradesh (*viz*, Maize-Chickpea, Maize-Potato-Wheat, Maize-Toria-Maize, Maize-Maize, Soybean-Maize, Maize+Soybean-Maize, Maize-Wheat). The total energy input was highest in Maize-Potato-Wheat while lowest was recorded in Maize-Lentil. The highest total energy output was recorded under Maize-Toria-Maize. The net energy gain was highest in Maize+ Soybean-Maize.

The yield energetics and economics of 5 legume based cropping sequences evaluated at Ranchi recorded that the stylo-wheat sequence recorded significantly maximum output energy for both economical and biological yields due to higher energy value of forage component. This sequence was also found more efficient in energy utilization and productivity followed by black gram- wheat sequence. The results are in accordance with the findings of Sanjaykumar and Prasad (1999) [55] at Ranchi.

Mandal *et al*. (2002) carried out the study on the bioenergy and economic analysis of soybean-based crop production systems in Central India and examines the energy requirement and energy input-output relationship of soybean - based crop production systems *viz*., Soybean (*Glycine max* (L.) Merrill) - Wheat (*Triticum aestivum* L.), Soybean-Mustard (*Brassica juncea (*L.) and Soybean - Chickpea (*Cicer arietinum* L.) in central India. Using a pre-tested questionnaire, 135 farmers were selected through a random sampling technique. Results revealed that manures and chemical fertilizers (50.87%), seedbed preparation (18.30%) and sowing management (17.69%) consumed the bulk of the energy (operational and non-operational) for all crops; it was highest in Soybean-Wheat and the lowest in Soybean-Chickpea. Though the net return from Soybean-Wheat was marginally higher than other systems, the Soybean-Chickpea system is more suitable in the central ecological niche of India due to its low requirement for non-renewable resources, higher EUE and benefit-cost ratio.

The conjuctive use of inorganic fertilizers and organic manure's (FYM) and biofertilizers to Sorghum followed by Chickpea during both the years showed higher values of energy output, energy balance, energy balance per unit input and energy output per input ratio of cropping sequence was reported by Gawai (2003) [20] in Sorghum- Chickpea sequence.

The field experiment conducted during 2001-02 at Indore, Madhya Pradesh, India by Billore and Joshi (2004) [7] to find out the effect of conjunctive use of organic, i.e. soybean residue and Farm yard manure and inorganic sources of nutrients in Soybean - Wheat cropping system and recorded that application of farmyard manure @ 5 tonnes / ha showed the highest net energy output (6.576 MJ/ha), energy - use efficiency (1.23), energy productivity (83.62 g/ MJ). Application of soybean residue @ 5 tonnes/ha was most energy- intensive (1.12) MJ/Rs). The maximum net energy output (4.998 MJ/ha) was recorded with 50% recommended level of fertilizers.

The study conducted on the effect of tillage and crop residue management on energy relations in greengram under four maize-based cropping systems in an Inceptisol of Delhi by Meena *et al*. (2006) [37] revealed that the when no residue was added, conventional tillage required 20% higher energy inputs than the zero tillage as more operations were performed in conventional tillage as compared to zero tillage, while the residue addition increased the energy output in both tillage practices. Komleh *et al.* (2012) [38] collected data from 300 farmers by a face to face questionnaire and revealed that total energy consumption was higher with chemical fertilizers (49%) especially nitrogen (40%) and followed by seed with share of 24%. It was found that the contribution of indirect energy was higher than that of direct energy and also the proportion of non-renewable energy was more than renewable resources.

Prajapat *et al*. (2015) [51] carried out field experiment for two consecutive years at Indian Agricultural Research Institute, New Delhi for the evaluation of soybean-based cropping systems with five nutrient supply options with respect to energy parameters and found that Soybean-Chickpea-Fodder sorghum system recorded highest net energy (339.9x 10^3 MJ ha^{-1}), energy efficiency (9.56), energy profitability (179 g MJ^{-1}), energy intensiveness (6.76). Among the nutrient supply options, application of 50% RDF + 50% RDN through FYM accounted for the highest energy output (286.1 MJ ha^{-1}), net energy (240.3 MJ ha^{-1}).

The highest non-renewable energy and total energy input was associated with conventional tillage. Renewable energy to non- renewable energy ratio and renewable energy percentage to total energy input were the maximum in no till. The lowest energy intensiveness was associated with minimum tillage. The gross and net energy output and renewable energy use efficiency were the maximum in conventional tillage. Soybean-chickpea system had an edge over soybean-wheat in case of renewable energy productivity and intensiveness. The application of organic manure either alone or in conjunction with mineral fertilizer significantly increased the renewable energy share while just reverse with alone application of mineral fertilizers. The integration of organic and inorganic source of nutrients production highest energy outputs. The highest renewable and non- renewable energy use efficiency was recorded with recommended dose of fertilizer and poultry manure alone respectively. Application of recommended dose of fertility showed the highest renewable energy productivity. The integration of organic manure with recommended dose of fertilizer showed higher energy intensiveness than their alone application of organic manure as reported by Billore *et al.* (2009) [8].

The highest total energy input was recorded in Maize (green cob)-Broccoli-Potato (57.03 × 10^3 MJ/ha) followed by Maize (green cob) + Asparagus bean-Radish-Onion (49.64 × 10^3 MJ/ha) and Maize (Green cob) + Asparagus bean-Broccoli-Radish (43.95 × 10^3 MJ/ha). The highest energy input was added through fertilizers (46.5% to 60.4%) followed by FYM (16.4-24.9%) and seed (1.4% to 22.9%). The energy output and energy productivity was also higher in Maize (green cob) +French bean-Pea-Summer squash (0.8 kg/MJ) and Maize + Asparagus bean-Radish-Onion (0.8 kg/MJ). It was also found that the energy use efficiency was at par in Maize + French bean- Pea-Summer squash (12.2 MJ/ha) and Maize-Wheat (*Triticum aestivum* (L.) cropping system (12.9 MJ/ha)(Negi *et al.*, 2016).

Lal *et al.* (2020) [34] conducted a field study to quantify the energy budgeting of different establishments methods, cultivars and dry season crops that are suited for rice fallowed lands and found that dry-seeded rice (DSR) reduced 18.4% energy consumption and transplanted rice (TPR) in which major energy saving was in diesel (60%), machinery and labour (66%) making DSR more energy profitable with a minor yield penalty.

Bazaluk *et al.* (2021) [4] conducted a study which aims at develop a model for energy and environmental assessment of straw production, taking into account t of its life cycle and direct energy input (Fuels, electricity, etc.,) indirect energy input (Fertilizer, herbicide, etc) and energy requirement in manufacturing agricultural factors and implements.

Manoj *et al.* (2022) [36] reported that concerning various inputs contribution to total energy input, chemical fertilizers were identified as a major contributors (73 and 47%) followed by FYM (20 and 22%) used to cultivate crops respectively. Overall, cereal + legume cropping systems performed well in terms of energy efficiency. Singh *et al.* (2008) [57] in their study on energy-use efficiency and economics of soybean based cropping system under the rainfed conditions in North-West Himalayan Region and results revealed that the maximum energy was consumed in terms of chemical fertilizers, followed by seed and plant protection chemicals, in all cropping systems.

Birendra Kumar and Karmakar (2015) [16] in their two year *rabi* season study on the effect of tillage and nutrient management on the energetics of oat recorded that among the nutrient managements, 125 per cent RDF recorded significantly higher gross energy output (146069 MJ/ha), net energy output (132245 MJ/ha) and energy use efficiency (10.56).

The multifarious relationships between nitrogen application and energy consumption are still not well understood in irrigated potato production system. There is a need to ensure that N and energy use are closely considered to provide useful options for adaptation and to build resilience at the farm level. A field experiment was conducted during the winter (November-March) of 2012-13 and 2013-14 at the District Seed Farm, Adisaptagram, Hooghly, West Bengal, India (23°26′N latitude and 88°22′E longitude with an altitude of 12 m above mean sea level) under sub-humid sub-tropical climatic condition of West Bengal, India by Banerjee *et al.* (2017) [2] and results showed that net energy gain (NEG) was the highest with the supply of 225 kg N/ha for both Kufri Himalini and Kufri Jyoti, and 150kg N/ha for Kufri Shailja. However, maximum values of energy ratio (ER), specific energy (SE) and energy intensiveness (EI) were recorded with 300 kg N/ha for all three tested cultivars.

Prajapat *et al.* (2018) [52] evaluated soybean-based cropping systems with five nutrient supply options with respect to energy parameters.

Among the nutrient supply options, application of 100% RDF accounted for highest energy consumption (46.7 × 10 MJ ha). The substitution of part of RDF through organic manure and/or biofertilizers resulted in reduced energy requirement for fertilization. The nutrient supply combination having 25% RDF along with 50% RDN through FYM and biofertilizers required least energy input (42.0 × 10^3 MJ ha^{-1}). Application of 50% RDF + 50% RDN through FYM accounted for the highest energy output (286.1 MJ ha), net energy (240.3 MJ ha) and energy output efficiency (968 MJ ha day) as compared to 100% RDF.

The calorific energy output was highest under soybean-Chickpea-fodder sorghum cropping system (370.7 x 10^3 MJ ha^{-1}) followed by soybean-wheat-mungbean cropping system (251.8 X 10^3 MJ ha^{-1}). The wheat and sorghum crops in these systems showed high response to added fertilizers and irrigations, produced more biomass than potato and chickpea, consequently gave higher energy output from respective cropping systems.

The higher bio-energy output from wheat and maize crops due to production of higher biomass was also reported by Singh *et al.*, (1997) [59]. and Jain *et al.* (2015) [24]. Owing to higher energy output, soybean-Chickpea fodder sorghum cropping system recorded highest net energy (331.9 X 10^3 MJ ha^{-1}), energy efficiency (9.56). This indicated that this cropping system requires high energy input to produce a unit output. Despite of high energy consumption, the soybean-chickpea-fodder sorghum system had the capacity to convert the input energy into higher biomass production and resulted in higher use efficiencies.

Ramesh *et al.*, conducted a field experiment to evaluate the effect of resource conservation technologies on productivity, nutrient acquisition and energetics of maize based cropping system and revealed application of crop residue mulch and INM resulted in significantly higher system energy input.

The field experiment was conducted during 2006-2008 at the Indian Agricultural Research Institute, New Delhi by Raman Jeet Singh and I.P.S. Ahlawat (2015) [54] conducted two experiments 1. Cotton based intercropping system involving peanut during summer/rainy season/Kharif season followed by wheat during winter/dry season/*rabi* season during 2006-2007 and 2007-2008.In an experiment 2 peanut was grown as a pure stand followed by wheat during 2006-2007 and 2007-2008.In experiment 1, eight treatments comprised of combination of two cropping systems) sole cotton and cotton+ peanut) and four fertility levels (control, 100% DN through Urea, 75%RDN through Urea + 25% RDN through FYM and 50% RDN through Urea+ 50% through FYM to cotton were laid out in a randomized block design with three replications. The succeeding experiment of wheat, the main plots were sub-divided into four plots to accommodate doses of N (0, 50, 100 and 150 kg ha-1) to wheat in a split plot design to assess energy budgeting in transgenic cotton-wheat cropping system and found that the energy use efficiencies of transgenic cotton-wheat production system can be enhanced by inclusion of peanut as an intercrop and substitution of 25% RDN of cotton through FYM, as well as application of 100 kg ha^{-1} to succeeding wheat crop. Fertilizers consumed bulk of the energy of all the three cropping systems. Peanut addition in cotton-wheat system increased the share of renewable energy inputs from 18 to 21%. Cotton+peanut-wheat system significantly produced 29% higher outputs over sole-cotton-wheat system and recorded higher net energy return, energy ratio, human energy profitability, energy productivity respectively over sole cotton-wheat system. However, sole cotton-wheat system maintained 17% higher energy intensiveness over cotton+peanut-wheat system. Among fertility levels, FYM containing treatments consumed relatively less energy than 100% RDN by urea only and share of renewable energy resources was in the range of 21-37%.

Inappropriate agricultural practices consume more input energy which cause global warming and climate change, thereby threatening environmental sustainability to identify energy efficient variety under various nutrient management practices undertaken during the *Kharif* season of 2018 and 2019 in a split plot design with three varieties of fodder maize (African Tall, J-1006 and P-3396) and four nutrient management practices such as N0: Absolute control, N1: 100% RDF, N2: 75% RDF + plant growth promoting rhizobacteria (PGPR) + Panchagavya spray and N3: 50%RDF + 25% FYM + PGPR + Panchagavya spray and showed that variety J-1006 recorded highest total energy output (224123 MJ ha^{-1}), net energy (211289 MJ ha^{-1}), energy use efficiency (17.64), energy productivity (0.98 kg MJ^{-1}), energy profitability (16.64).It was also observed by the researcher that nutrient management 75% RDF + PGPR+ Panchagvya spray showed highest total energy output (229, 470 MJ ha-1) and net energy (215, 482 MJ ha1). However, energy use efficiency, energy productivity, and energy profitability were significantly higher with integrated nutrient management (N2 and N3) over 100% RDF. The results are accordance with the findings of Kumar *et al.* (2023) [30].

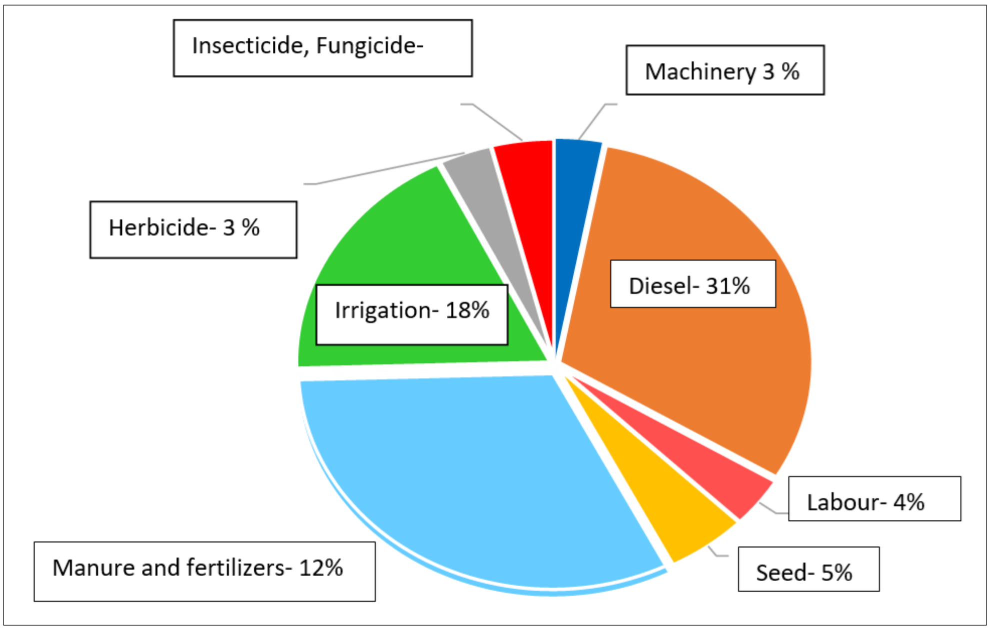


Fig 4: Source-wise mean share of inputs energy used for fodder maize (Kumar *et al.*, 2023) [30].

Nutrient management accounted for the maximum share (32%), followed by field preparation (23%), water management (19%), and sowing (15%). Nevertheless, the contribution of harvesting, plant protection, and weed management was ≤4% in this study.

Nitrogen fertilisation and diesel fuel consumption were identified as the most energy intensive inputs as reported by Moitzi *et al.* (2021) while investigating energy efficiency for sugarbeet and soybean.

Kumar *et al.* (2009) [31] examined the effect of different integrated nutrient management options in two most popular cropping systems *viz.*, Rice-Potato-Onion and Maize-Potato-Green gram of eastern plains at Central Potato Research Station, Patna during 2004-2007. It includes treatment with different dose of fertilizers and 100% organic treatment (Farm yard manure to replace recommended dose of N to all crops). Along with this, it includes other treatments like reduced doses of nutrient to subsequent crops, recycling of crop residue and application of FYM. The Maize- Potato-Green gram sequence gave higher potato yield due to improved soil physical conditions. Results indicated the possibility to economize fertilizer in green gram crop but not in onion by replacing 50% NPK through FYM or potato crop residue, when grown on residual fertility of potato. However, residual incorporation of leguminous crop had more beneficial effect on subsequent maize crop but same effect of onion residue was not observed on rice.

Meena *et al.* (2006) [37] conducted study on the effect of tillage and crop residue management on energy relations in greengram under four maize-based cropping systems in an Inceptisol of Delhi. They observed that when no residue was added, conventional tillage required 20% higher energy inputs than the zero tillage, while the residue addition increased the energy output in both tillage practices.

The data collected from 300 farmers by a face to face questionnaire revealed that total energy consumption was higher with chemical fertilizers (49%) especially nitrogen (40%) and followed by seed with share of 24%. It was found that the contribution of indirect energy was higher than that of direct energy and also the proportion of non-renewable energy was more than renewable resources Komleh *et al.* (2012) [38]. Sharma *et al.* (2018) [56] conducted study to estimate energy consumption for rainfed potato production and revealed that contribution of indirect energy was higher than that of direct energy and also the proportion of non-renewable energy was more than renewable resources. Lal *et al.* (2020) [34] conducted a field study to quantify the energy budgeting and productivity of different establishments methods, cultivars and dry season crops that are suited for rice fallowed lands and found that dry-seeded rice (DSR) reduced 18.4% energy consumption and transplanted rice (TPR) in which major energy saving was in diesel (60%), machinery and labour (66%) making DSR more energy profitable with a minor yield penalty.

4. Conclusion

From the study, it was concluded that the legume based cropping system consumed less energy inputs than cereal based system. Also, energy input: output ratio decreased with the addition of N fertilizers. Enhancement in the energy efficiency in agricultural practices is essential and can be achieved by minimizing energy-intensive operations such as tillage and optimizing application of fertilizer in crop production system. The application of 100% RDN application through urea maintained highest energy intensiveness in comparison to FYM treatments. Among the various inputs, total energy consumption was higher with chemical fertilizers (49%), especially N (40%) followed by seed with share of 24%.

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