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Energy Footprints of Rice Production

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FOREWORD

Rice is the foremost staple food of India ensuring national food and nutritional security. Rice farmers, however, are facing challenges to increase production and income with increased cost of cultivation and labour shortage. With the emerging challenges of climate change and declining land-holding, the situation is expected to aggravate further. To enhance farm productivity and profitability, mechanization of small farms and optimum utilization of energy for various farm operations should be ensured. This demands due attention to prioritize optimum farm mechanization. This step would help the rice farmers in maximizing energy use efficiency as well as energy profitability.

The bulletin on"Energy Footprints of Rice Production" is an attempt to provide holistic information about operational energy consumption of rice production system. This will help the stakeholders in selecting the right farm operations, tools, machineries and implements for maximizing farm output with optimal input.

I appreciate the efforts of the authors in bringing out this bulletin and hope that the farmers, researchers, planners and extension agents will find this publication useful.

(H. PATHAK)
Director, NRRI

PREFACE

Rice is a staple food for nearly half of the world population and 3/4th of Indian population. The burgeoning population is putting pressure on producing more food from the limited natural resources. Farm income is also declining rapidly due to increasing cost of farm inputs including labour. Average land holding size in India is expected to decrease to 0.68 ha in 2020 and 0.32 ha in 2030. In India, rice is being grown in various ecologies comprising of irrigated and rainfed systems. Cultivation of rice in these ecologies involve various inputs in terms of human, animal, mechanical or chemical energies. Farm mechanization has the potential to cope up with the ever-rising food demand by reducing cost of cultivation and producing more crops per unit land. Optimization of energy sources is essentially required for making farm production cost effective and environment friendly. Optimization of farm input energies is possible only when the associated energy with various farm operations is worked out.

Energy footprint is the equivalent energy associated with various farm operations. On quantification of energy footprints, one can choose the most efficient energy sources to maximize the yield by spending less input cost to various farm operations. In this bulletin, the energy footprint associated with various farm operations in rice cultivation has been worked out for easy comparison of energy use under different farm operations, which will help in selecting the appropriate climate-resilient energy efficient technologies, machineries, tools and implements by rice growers for enhanced profitability.

We hope that this bulletin will be useful to rice farmers as well as researchers, extension workers and policy makers in understanding the energy requirement of different farm implements and identifying energy efficient farm machineries.

Authors

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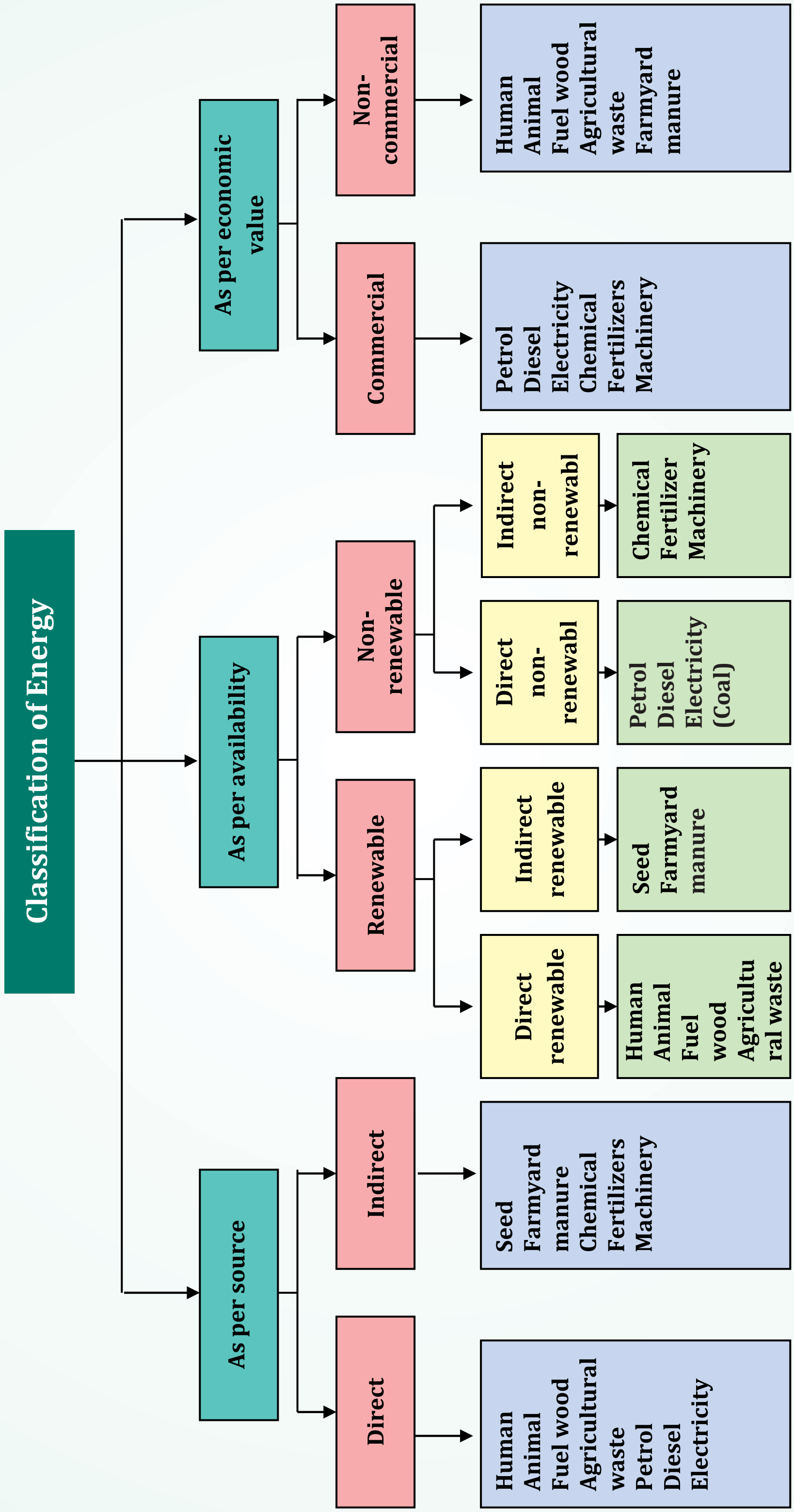
1. Introduction

Farm productivity depends considerably on power availability and its efficient use. Agriculture requires energy as an essential input to production (Lal *et al.* 2013), enhancing food security, adding value (Karimi *et al.* 2008) and contributing to rural economic development (FAO 2000). Energy requirement in agriculture sector depends on the size and quality of cultivated land, level of mechanization, cropping pattern and climatic conditions. Agriculture uses large quantities of locally available non-commercial energy, such as manure and animal energy, and commercial energy directly and indirectly in the form of seed, diesel, electricity, fertilizer, plant protection chemicals, irrigation water, machinery etc. (Singh 2002; Alam *et al.* 2005; Iqbal 2007). Maximum benefits in agricultural production can be obtained through optimal and proper utilization of energy inputs involved in various farm operations. As per the size of land holding and method of crop cultivation, selection of energy efficient technology is important. Mechanical power helps in timely farm operations with low labour cost. Food grain productivity has a direct relationship with farm power availability; higher the power availability more is the productivity. Over these years there has been a rapid shift in farm power use from animal power to mechanical power. Farm power availability and productivity of Indian agriculture increased from 0.25 to 1.84 kW ha^{-1} and from 0.52 t ha^{-1} to 1.92 t ha^{-1}, respectively from 1951 to 2012. Farm power availability and productivity in India is projected to increase 2.2 kW ha^{-1} and 2.3 t ha^{-1}, respectively by 2020 (Mehta *et al.* 2014).

Rice is a staple food crop for major population of India, which at present occupies around 44 Mha (22%) of cropped land. India is the second largest producer (103.36 million tones in 2015-16) next only to China which contributes 21.5% of global rice production. The rice demand in India to be increased to 156 Mt by 2030 (ICAR, 2010). Among different rice growing ecologies, irrigated systems are considered to be more favourable than the rainfed systems. Rainfed system has again a wide range of subsystems like shallow, mid and deep water rainfed lowlands and rainfed uplands. The growing demand of rice grain has to be met by producing more rice using less land, water, manpower and optimising all agricultural input usages (energy inputs). An increase in production and productivity of rice crop will increase use of various input energies, such as fertilizer, irrigation water, diesel operated irrigation pump, plant protection measures, chemicals, electricity etc. At present farm activities related to rice production depends mainly on energy from non-renewable energy sources viz. fossil fuels, which are limited in nature. Major manual operated implements owned and used by farmers are drum seeder, transplanter, pedal operated thresher, hand operated sprayer-duster, cono-weeder etc. The bullock drawn implements owned and used in rice cultivation are wooden plough, mould board plough, disc harrow etc. Tractor operated implements is being used for dry field preparation as well as for pudding the rice field. Use of power operated sprayer & duster; thresher has also increased at a faster rate.


Classification of Energy
As per source
As per availability
As per economic value
Direct
Indirect
Renewable
Non-renewable
Commercial
Non-commercial
Direct renewable
Indirect renewable
Direct non-renewabl
Indirect non-renewabl
Human Animal Fuel wood Agricultural waste Petrol Diesel Electricity
Seed Farmyard manure Chemical Fertilizers Machinery
Human Animal Fuel wood Agricultural waste
Seed Farmyard manure
Petrol Diesel Electricity (Coal)
Chemical Fertilizer Machinery
Petrol Diesel Electricity Chemical Fertilizers Machinery
Human Animal Fuel wood Agricultural waste Farmyard manure

Selection of different methods of crop production based upon ecologies and post harvest operations will affect the total energy requirement of crop production. Mainly three methods are employed for paddy cultivation in India, namely, (i) dry direct sowing (ii) wet direct sowing and (iii) transplanting. These methods of crop establishment have different energy requirements for field preparation, crop establishment, weeding, harvesting etc. The best way to achieve higher rice productivity along with environmental sustainability is to work out the energy foot prints involved in various farm operations related to rice cultivation so as to maximize the productivity by optimizing the energy used by various farm operations. This is possible through study of the energy-use pattern analytically relevant to various farm operations. Non-productive energy use in rice production can be controlled by planning and optimizing the energy use efficiency of methods and techniques of rice cultivation. The aim of the bulletin is to discuss the energy foot prints of various farm operations related to rice cultivation, which can be helpful to policy makers, farmers and other stake holders to take better decision for selection of farm implements/ tools/ machines/ operations in order to achieve higher farm output per unit consumption of input energy.

2. On-farm power sources

2.1 Man power

Manpower is one of the most important power sources on the farm. Energy equivalent for an adult man is taken as 1.96 MJ h^{-1} and for Woman 1.57 MJ h^{-1}.

2.2 Animal power

Animal power is the major power source on the farm to perform the activities like tillage and sowing. The energy equivalent for large, medium and small size of bullock is taken as 14.05, 10.10 and 8.07 MJ h^{-1}.

2.3 Mechanical power

Tractor and diesel/petrol engine are used as a mechanical power source to operate the agricultural machinery and to lift the irrigation water. Fuel consumption for operating various machinery is measured on the research farm and at farmer's field by top fill method.

2.4 Electrical power

The electrical input for an electric motor may be determined from the following formula.

$$E = RHP \times 0.746 \times E_r$$

Where,

E= Electricity input, kWh

RHP= Rated power of the electric motor, hp

E_r = Efficiency of motor, decimal

Electric input may be noted in terms of units (1.0 unit=1 kWh) from energy meters installed with the motor.

3. Energy conversion coefficients

Data for all the farm inputs used and the output (paddy and straw yield) were collected and then converted into equivalent energy values using appropriate conversion coefficients.

Table 1. Energy conversion coefficients (MJ unit^{-1}) for the different inputs and outputs

Particulars	Unit	Energy Equivalents (MJ unit^{-1})
Human labour	h	1.96 (1 Adult Women =0.8 Adult man)
Diesel fuel	l	56.31
Petrol	l	48.23
Electricity	kWh	11.93
Bullock (medium size)	pair-h	10.10
Nitrogen (N)	kg	60.60
Phosphorus (P_2O_5)	kg	11.10
Potassium (K_2O)	kg	6.70
Self - propelled machinery	kg	64.80
Electric motor	kg	64.80
Tractor	kg	68.40
Farm machinery	kg	62.70
Seed/Grain (paddy)	kg	14.70
Straw (paddy)	kg	12.50

4. Specific mathematical models for calculating energy balance

Energy Input =Human energy +Fuel energy+Machine energy

Human energy

$$= \text{Useful man hour spent in operation} \times \text{man energy factor } (MJ\ kg^{-1})$$

Fuel energy=Fuel consumption $(lh^{-1}) \times$ *Energy factor for diesel* $(MJ\ l^{-1})$

Machinery energy

$$= \text{Weight of the machine(kg)} \times \text{Self propelled machine energy equivalent factor } (MJ\ kg^{-1}) \times \text{Useful working hours } (h\ ha^{-1}) \times \text{Useful life of machine}$$

Energy output

$$= [\text{Total grain production} \times \text{grain energy equivalent factor}] + [\text{Total straw production} \times \text{straw energy equivalent factor}]$$

The net energy gain and energy profitability were calculated as

$$\text{Net energy gain} = \text{Energy output } (MJ\ ha^{-1}) - \text{Energy input } (MJ\ ha^{-1})$$

$$\text{Energy profitability} = \frac{\text{Energy output } (MJ\ ha^{-1}) - \text{Energy input } (MJ\ ha^{-1})}{\text{Energy input } (MJ\ ha^{-1})}$$

5. Energy involvement in different rice cultivation methods

Basically, in Eastern India rice is grown by adopting three methods i.e. dry direct sowing (DDSR), wet direct sowing (WDSR), and transplanting. In order to estimate energy efficiency of different rice growing methods, the energy input involved with different machines and their performance was evaluated.

5.1. Dry direct seeding of rice (DDSR)

DDSR refers to direct sowing of rice seeds in the dry field rather than by transplanting seedlings from the nursery. For field preparation tillage operations were performed by implements which may be operated by either bullock, tractor and power tiller. After field preparation rice seeds can be directly sown in the field using seed drill or by manual broadcasting. In broadcasting method 80 to 100 kg ha^{-1} while in line sowing 40 to 60 kg ha^{-1} seeds were required. Total energy required for complete the tillage operation for DDSR with different combination of implements (Table 2) and energy requirement for sowing operation with different methods are discussed here (Table 3).

The data used for calculating the input energy was adapted from report of energy requirement in agriculture sector AICRP on EAAI ICAR-NRRI Cuttack.

Table 2. Energy requirement (MJ ha^{-1}) for field preparation in dry direct sowing of rice

Machinery (No of passes)	Human	Fuel/ Bullock energy	Machinery	Total
Bullock – MB plough (1) + Indigenous plough (2)+ laddering (1)	162.68	838.30	70.22	1071.20
Bullock – MB plough (1) + Disc harrow (2)	88.20	454.50	54.34	597.04
Tractor - MB plough (1) + Cultivator (2)	18.03	2075.58	145.01	2238.63
Tractor - MB plough (1) + Disc harrow (2)	16.26	2082.90	133.32	2232.50
Tractor - Cultivator (2) + Disc harrow (2)	17.83	1978.17	141.93	2137.93
Tractor - MB plough (1) + Rotavator (2)	18.03	2261.41	186.95	2466.39
Power tiller	38.22	1244.45	51.35	1334.02

Table 3. Energy requirement (MJ ha^{-1}) for dry-direct sowing of rice

Sowing methods	Human	Fuel / Bullock	Machinery	Seed	Total
Manual broadcasting	14.89	NIL	NIL	1470	1484.89
Sowing behind animal plough	49.00	252.50	18.81	1176	1496.31
Bullock seed drill	21.16	109.08	33.85	1176	1340.10
Manual seed drill	54.88	NIL	17.55	882	954.43
Tractor drawn seed drill	4.11	388.53	31.81	882	1306.47
Power tiller seed drill	16.66	551.83	128.79	882	1579.29

Plate 1. Field preparation using tractor drawn mould board plough (a) and cultivator (b) for dry direct sowing of rice

Plate 2. Field preparation using power tiller for dry direct sowing of rice

Plate 3. Sowing by tractor drawn seed cum fertilizer drill (a) and three row manual seed drill (b)

5.2. Transplanting

5.2.1 Nursery management

For manual transplanting of rice, nursery was prepared in field and for mechanical transplanting, mat type nursery was prepared using seedling tray or seedling frame in field. For manual transplanting of 1 hectare land, 800 m^2 area was required for nursery preparation. Assured water supply and efficient drainage system were supplied for good quality rice nursery. For nursery preparation selected area of field should be ploughed twice followed by two puddlings in weekly interval and levelled by available power source i.e. animals, power tiller or tractor. After preparation of land sprouted seeds were uniformly spread over the surface and in 20-25 DAS seedlings were pulled out for transplanting. For mat type nursery seedlings are established in a layer of soil mix, arranged on a firm surface i.e. Concrete floor/ polythene sheets on field/ seedling trays. Seedlings are ready for planting within 14-20 days after seeding (DAS). For nursery preparation of traditional method transplanting (manual transplanting) total energy required is 1446 MJ ha^{-1} and for mat type nursery preparation 1258 MJ ha^{-1} energy is required. Details energy requirement for preparation of nursery are given in table 4.

Table 4. Energy required (MJ ha^{-1}) for nursery preparation

Operation	Human	Seed	Fertilizer	Machinery	Diesel	Total	
Manual transplanting	Nursery raising + uprooting	218.18	882.0	295.12	5.47	45.04	1445.81
Mat type nursery	Nursery raising	376.32	882.0	--	--	--	1258.32

Plate 4. Mat type nursery preparation in GI sheet tray

5.2.2 Conventional transplanting method

Manual transplanting of rice is mostly practiced in India and particularly in Odisha. On an average after 20 to 25 DAS, rice seedlings are uprooted from nurseries and transplanted in main field at the rate of 2-3 seedlings per hill. This process is highly labour intensive, tedious and tiresome. During the transplanting operation, a person has to stand in puddled field for long hours with frequent change in their posture which may cause musculo-skeletal disorder. Besides, the root washing of seedlings is labour intensive and adds up to the cost of transplanting.

5.2.3. Manual transplanter for mat type nursery

Because of the higher efficiency of the manual transplanter, it is quite useful for marginal and small farmer as the conventional transplanting is highly labor intensive operation. The manual transplanter is comprised of floats, a main frame assembly made of MS pipe that supports the seeding tray made of G.I sheet, pushing lever tray indexing mechanism, picker bar assembly and handle. The transplanter operated by single operator more effectively works in puddled fields having no standing water. The transplanter is operated in the field by push-pull action. Operator is involved in multitasking during the operation of transplanter, first move backward, pull the machine and simultaneously push the handle to cut the nursery and planting in soil. The field conditions should be ideal for better performance of transplanter. Manual rice transplanter can be used for timely operation and reduced cost of cultivation as compared to conventional transplanting.

5.2.4. Mechanical transplanter

Use of mechanical paddy transplanters has been increasing in the country due to shortage of labour. The farmers have come forward for adoption of transplanting with self-propelled paddy transplanter. But due to small land holding and poor economic condition of farmers, they cannot purchase the machine instead they adopt the technology on custom hiring basis. The use of self-propelled transplanter provides economic benefits to the farmers over the manual transplanting methods. The details of total energy required for complete tillage operation for transplanting with different combination of implements and energy requirement for sowing operation under different methods are presented as Tables 5 & 6. The data used for calculating the input energy was adapted from report of energy requirement in agriculture sector AICRP on EAAI.

Table 5. Energy requirement (MJ ha^{-1}) for field preparation in transplanting

Machinery/implement Used (No of passes)	Human	Fuel / Bullock	Machinery	Total Energy required
Bullock – MB plough (1) + Disc puddler (3)	142.88	438.20	62.22	643.30
Tractor - Dry Cultivator (2) + Wet Rotavator (2)	35.28	2772.50	417.11	3224.9
Tractor - Dry Cultivator (2) + Wet cultivator (2)	40.57	2816.72	454.71	3312.6
Tractor - Dry MB plough (1) + Wet Disc puddler (2)	21.75	2060.72	171.33	2253.8
Power Tiller	53.50	1853.02	20.54	1927.22

Table 6. Energy requirement (MJ ha^{-1}) for transplanting

Macinery/ implement Used	Human	Fuel	Machinery	Nursery preparation	Total Energy required
Transplanting by hand	533.80	--	--	1445.81	1979.61
Manual drawn 4 row transplanter	123.48	--	79.00	1258.32	1460.80
Power operated eight row transplanter	49.00	281.55	31.19	1258.32	1620.06


(a)


(b)

Plate 5. Puddling operation using animal drawn disc harrow (a) and tractor rotavator (b)


(a)


(b)

Plate 6. Transplanting of rice by 8 row mechanical transplanter (a) and four row manual transplanter (b)

5.3 Wet direct seeding of rice (WDSR)

In wet direct seeding, pre-germinated paddy seeds are broadcasted on well-puddled seedbeds with proper drainage. This method of sowing is more commonly used in irrigated areas. Field preparation operations for WDSR are similar as of transplanting. To avoid broadcasting, sowing of pre-germinated seeds by drum seeder is best option. Sowing with drum seeder saves seed, fertilizer and other inputs and maintains uniform row to row spacing for performing subsequent field operations (Teble 7). This method has economical and operational advantages over traditional planting methods, because it eliminates nursery raising, transportation and physical damage to the seedlings. It reduces the human drudgery in transplanting of paddy and reduces cost of cultivation. The data used for calculating the input energy was adapted from annual report of AICRP on EAAI.

Table 7. Energy requirement (MJ ha^{-1}) for sowing under wet direct sowing of rice

Methods/ machinery used	Human	Fuel	Machinery	Seed	Total
Manual broadcasting	15.68	NIL	NIL	1470	1485.68
Manual line sowing	203.62	NIL	NIL	882	1085.62
Eight row cup type power seeder	11.07	318.15	31.88	882	1243.10
Eight row conical drum type power seeder	11.81	339.38	34.95	882	1268.14
Eight row cylindrical drum power seeder	11.23	322.66	31.61	882	1247.50
Manual drawn six row cylindrical drum seeder	32.65	NIL	10.44	882	925.09
Manual drawn four row conical drum seeder	39.51	NIL	7.58	882	929.09
Manual drawn two row cup type drum seeder	89.08	NIL	14.24	882	985.33

Plate 7. Sowing of pre-germinated seeds with manual four row drum seeder (a), manual six row drum seeder (b) & power operated eight row drum seeder (c)

5.4 Energy requirement for weeding

Heavy weed infestation is one of the major constraints for the success of direct seeded rice (Farooq et al., 2011). In direct seeded rice, yield losses due to weeds are reported to be 70-80% (Hussain et al., 2008; Mahajan et al., 2009; Singh et al., 2007). For achieving higher rice production, proper control of weed is essential. Conventional hand weeding is both labour and time consuming and hence adds up to the cost of cultivation. Majority of the farmers are using traditional tools and equipment for weed control which involves drudgery, high cost of operation, wastage of agricultural inputs and damage to crop produce (Shrivastava, 2000). Mechanical control is one of the important classical weed management methods. It has some advantage over chemical weeding i.e. slow growth of weeds (Kwangwaropas, 1999) and no adverse effect on plant growth. The energy involvement in different weed control methods is presented in table 8. The data used for calculating the input energy was adapted from annual report of AICRP on EAAI.

Table 8. Energy requirements (MJ ha^{-1}) for different weed control methods

Methods/ machinery used	Human		Bullock/ Machinery	Fuel / chemical	Total
	Male	Female			
Hand weeding	NIL	1428.70	NIL	NIL	1428.70
Finger weeder	966.20	361.10	24.65	NIL	1351.90
Conoweeder	497.80	471.00	66.29	NIL	1035.00
Bullock drawn weeder	13.72	481.20	81.23	NIL	576.15
NRRI Single row power weeder for dry land	76.26	440.00	21.29	1175.21	1712.76
NRRI two row power weeder for wet land	29.00	472.00	47.95	611.20	1160.15
Two row power weeder for wet land	42.30	675.00	11.60	1041.70	1770.60
Chemical weeding	59.78	471.00	2.10	36.00	568.80

Plate 8. Weeding in rice with different mechanical weeders power operated two row wet land weeder (a) star cono weeder (b) power operated single row dry land weeder (c) & finger weeder (d)

5.5 Fertilizer application

Broadcasting is the normal practice of fertilizer application in rice cultivation. Normally, fertilizer nitrogen @ 80 kg ha^{-1} is applied in 3 split doses as 50% basal, 25% at maximum tillering and 25% at panicle initiation. Among other methods of applying nitrogen placement of urea briquettes/ pellets at 7-10 cm soil depth at the rate of one USG near the centre of each four rice hills is popular. Performance of urea super-granules and urea briquettes was found to be superior than sulphur coated urea, neem cake coated urea and prilled urea (Thomas and Prasad, 1987) in terms of yield and N uptake. Continuous operation type and non-continuous injector type applicators for deep placement of urea briquettes in transplanted rice were developed for this purpose. The continuous operation-type applicators were found labour saving as compared to non-continuous type applicators but several design related problems with respect to metering and depth of placement makes these applicators less efficient than the manual placement. Table 9 reflects the energy requirement (MJ ha^{-1}) for fertilizer application in rice.

Table 9. Energy requirement (MJ ha^{-1}) for fertilizer application in rice

Fertilizer application	Broadcasting	Deep placement
Human energy	47.04	123.48
Machine energy	NIL	59.25
Nitrogen (N)	4848	4848
Phosphorus (P_2O_5)	444	444
Potassium (K_2O)	268	268
Total	5607.04	5742.73


Plate 9. Deep placement of urea briquettes

5.6 Harvesting and threshing

The purpose of grain harvesting is to recover grains from the field and separate them from the rest of the crop material in a timely manner with minimum loss while maintaining good grain quality. Harvesting of paddy constitutes one the most labour consuming operation and is mostly done by human hands with the help of sickle. Generally, 170 to 200 man hours per hectare is being required for harvesting paddy crop. Non-availability of labour at the time of harvesting is a major constraints which hampers the timeliness in harvesting operation, resulting in over drying of crops in the field and shattering of grains causing yield losses to the extent of 5 to 15%.

Different types of harvesting methods are generally employed in various parts of the country. Wide variety of tools are used such as knives, sickles, self-propelled reapers, tractor-mounted harvesters and self-propelled combine harvester.

5.6.1. Serrated blade sickle

It consists of a wooden handle along with serrated blade. Serrated blade sickle cuts the crop by principle of friction cutting like in saw blade. The crop is held in one hand and the sickle is pulled along an arc for cutting.

5.6.2. Reaper

Power operated reaper is used for harvesting of crops mostly at ground level. It consists of crop-row divider, cutter bar assembly, feeding and conveying devices.

5.6.3. Combine harvester

The combine harvester combines all operations: cutting the crop, feeding it into threshing mechanism, threshing, cleaning and discharge of grain into a bulk wagon or directly into bags. Straw is usually discharged behind the combine in a windrow.

5.6.4. Drummy type thresher

This thresher has wire loop type threshing drum. The rotational power for threshing drum is supplied by 1.0 HP single phase electric motor through belt and pulley or it can be operated by paddle. The machine consists of a basic frame, threshing cylinder, prime mover and power transmission unit. Two persons are required to undertake the threshing operation. It is economical and suitable for threshing of paddy to small and marginal farmer.

5.6.5. Axial flow thresher

Axial flow thresher consists of the threshing cylinder, concave cylinder casing, cleaning system and feeding chute. It is used for threshing paddy and it works on the principle of axial flows, the crop is fed from one end and the straw is taken out from the other end after completing threshing of crop that is the flow of crop is along the direction of axis of the cylinder. Energy requirement for different methods of harvesting and threshing is presented in table 10.

Table 10. Energy requirement (MJ ha^{-1}) for harvesting and threshing

Implement / Machine	Human	Machine	Fuel/electrical	Total
Sickle	176.68	2.76	NIL	179.44
Reaper	11.76	17.58	394.17	323.51
Bundling	59.86	NIL	NIL	59.86
Drummy thresher (manual operated)	352.80	63.48	NIL	416.28
Drummy thresher (power operated)	58.80	35.26	133.49	227.56
Combine	7.84	342.76	1003.20	1353.80
Axial-flow thresher	31.36	105.80	846.45	983.61

Plate 10. Harvesting by reaper (a) and threshing by electric drummy thresher (b)

6. Classification of energy used in rice cultivation

To understand the energy consumption pattern of rice cultivation methods, energy use can be classified as per sources (direct and indirect energy), availability (renewable and non-renewable energy), on comparative economic value (non-commercial and commercial energy) and renewable and non-renewable energy can be subdivided into direct and indirect energy sources (Fig.1). The data used for calculating the input energy was adapted from annual report of AICRP on EAAI.

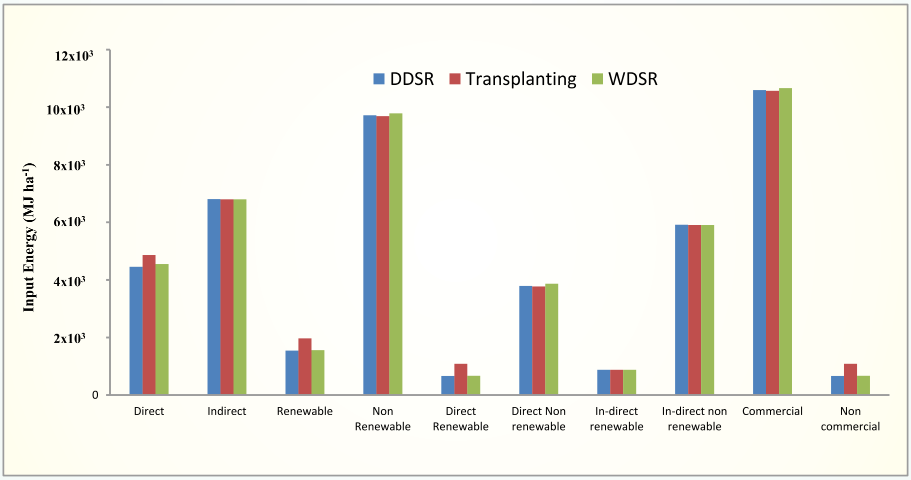


Fig. 1. Input energy under different methods of rice cultivation

6.1. Direct and Indirect energy use

India has witnessed a considerable decline in the use of animal and human power in agriculture related activities. The trend has paved a way for a range of agricultural tools. A large number of these are driven by fossil fuel operated vehicles such as tractors, diesel engines. This has resulted in a shift from the traditional agriculture process to a more mechanised process. These leads to major contribution of power availability in indirect energy and also non-renewable sources of energy. Indirect and direct sources of energy in paddy cultivation is in the range of 60% and 40% for DDSR, 61% and 39% for WDSR, 58% and 42% for transplanting, respectively (Fig. 2).

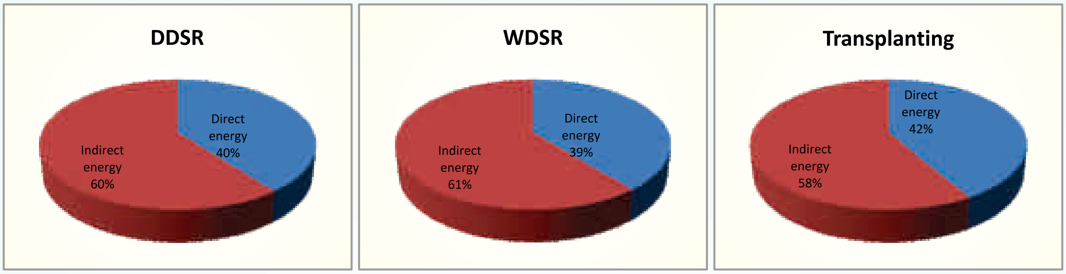


Fig. 2. Direct and indirect energy use under different methods of rice cultivation

6.2. Renewable and non renewable energy use

Tillage and threshing are the most mechanized operations in rice cultivation while other operations i.e. sowing, transplanting, weeding, fertilizer application, and harvesting uses low mechanization. Use of heavy machineries in rice cultivation leads to increased use of non-renewable source. In DDSR & WDSR the non-renewable source of energy utilization is about 86% and renewable energy 14%, and in transplanting non-renewable source of energy utilization 83% and renewable energy 17% (Fig. 3). Farm machinery helps in increasing the efficiency of farm labour and reducing drudgery and workloads. It is estimated that farm mechanisation can help in reducing time in field operation by approximately 15-20%. It also saves inputs and helps in the reduction of production costs and allows farmers to earn more income, that is why the use of non-renewable energy is high.

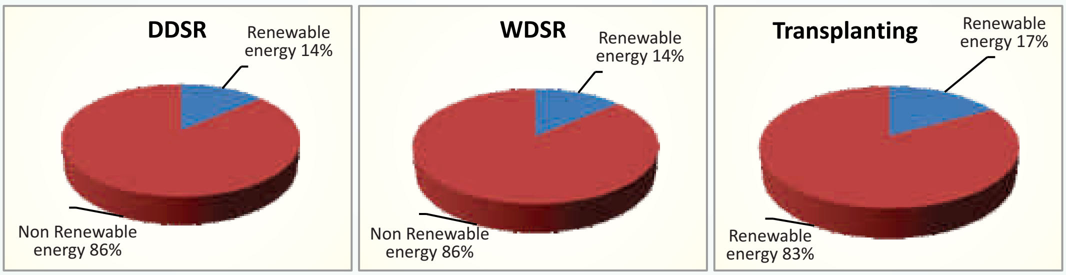


Fig. 3. Renewable and non-renewable energy use in different methods of rice cultivation

6.3. Commercial and non-commercial energy use

Agricultural wages have traditionally been low. Due to low productivity and rapid increase in wages, machine use in rice cultivation increased rapidly which resulted in major share of commercial energy than non-commercial energy (Fig. 4). The commercial and non-commercial energy use are 94% and 6% in DDSR and WDSR , but in transplanting due to requirement of more human labor energy use changes and becomes 91% commercial and 9% non-commercial energy use pattern.

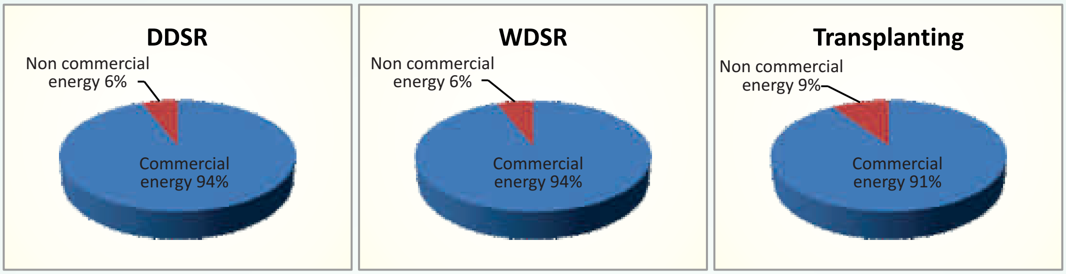


Fig. 4. Commercial and non-commercial energy use in different methods of rice cultivation

7. Energy use pattern in rice cultivation based on power sources

Traditionally, bullocks were main source of farm power in India. With the advancement of agricultural science, the scenario has changed and gradually the bullocks were replaced by mechanised farm implements. Now in small farms, power tiller is mostly used as prime mover for field preparation and large farms tractor is used with matching implements. Although bullock drawn rice cultivation practices are least energy intensive as compared to power tiller or tractor operated cultivation, but requires year-around maintenance, also is incapable of maintaining timeliness in operation. The energy use pattern under bullock powered DDSR method of rice cultivation showed 11.53% and 16.97% less energy consumption under power tiller and tractor operated cultivation practices, respectively (Fig. 5 & 6), whereas for transplanting method of cultivation the power tiller operation requires 17.74% more energy as compare to bullock operation and 19.63% more energy under tractor operation (Fig. 7 & 8). In the WDSR method of cultivation the energy consumption under power tiller and tractor operation was found to be more (28.42% and 30.57%, respectively), as compared to bullock powered farms (Fig. 9 & 10). Irrespective of power sources in all rice cultivation methods fertilizer is most energy consuming and ranges from 49-57 % for DDSR, 50-63% for transplanting and 52-68% for WDSR.

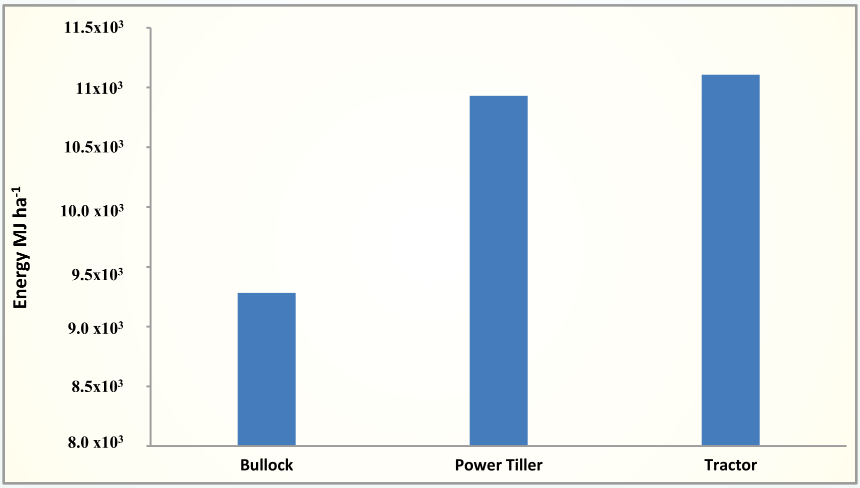


Fig. 5. Energy consumption (MJ ha^{-1}) in dry direct sowing of rice with different power sources

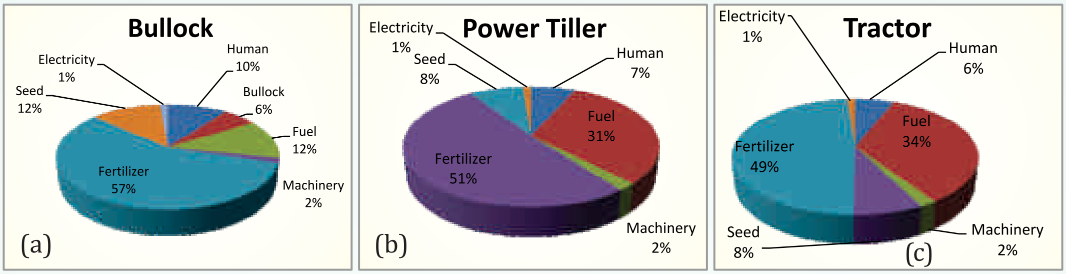


Fig.6. Component wise energy breakup in dry direct sowing of rice in bullock (a), power tiller (b) & Tractor, (c) powered farms

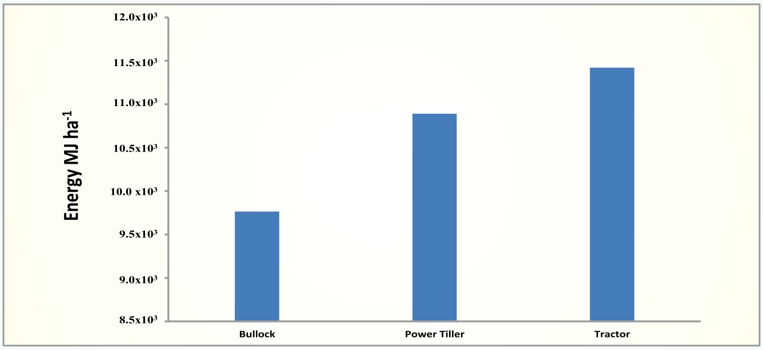


Fig. 7. Energy consumption (MJ ha^{-1}) in transplanting of rice with different power sources

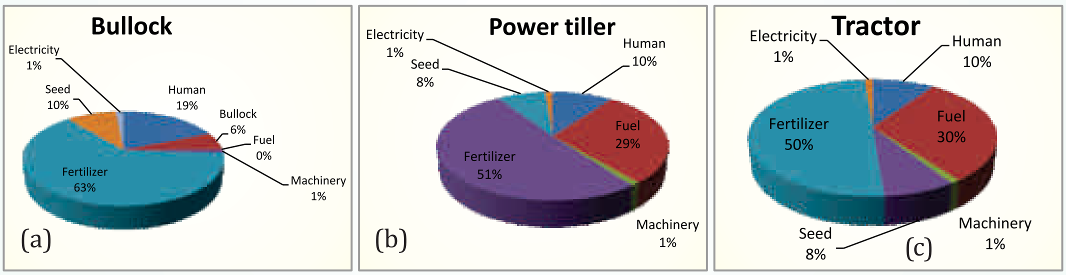


Fig. 8. Component wise energy breakup in transplanting in bullock (a), power tiller (b) & Tractor (c) powered farms

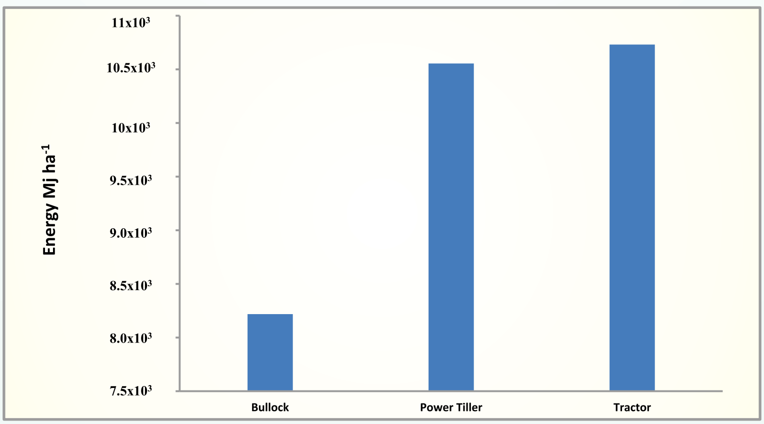


Fig. 9. Energy consumption (MJ ha^{-1}) in wet direct sowing of rice with different power sources

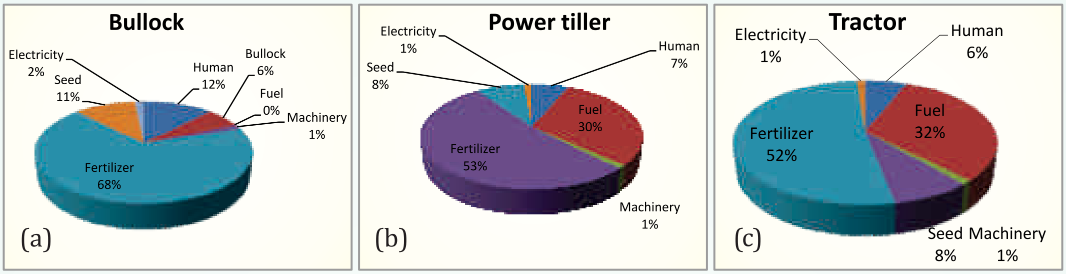


Fig. 10. Component wise energy breakup in wet direct sowing of rice in bullock (a), power tiller (b) & Tractor (c), powered farms

8. Energy efficient package of practices for rice cultivation

In rice cultivation use of machinery for field preparation is high and most of the farmers of India are using tractor and power tiller with matching implements for deep ploughing and puddling operations. But for other operations *viz.* sowing, transplanting, harvesting and threshing human labour or animals are used which leads to higher use of energy input in rice production. Optimal use of energy sources available in farm can reduce the input energy without affecting output. Based upon the estimation of energy footprints of rice cultivation improved package of practices which includes use of improved implements are recommended for cultivation of rice under different methods i.e. DDSR, Transplanting and WDSR (Table 11, 12 & 13).

Table 11. Improved cultivation practices for DDSR for optimal energy use

Type of Farm	Package of practices
Animal Farm	Bullock ploughing (M B Plough) x 1 + Bullock disc harrow x 2; sowing by bullock drawn seed drill; weeding chemical + mechanical + manual; FYM application by bullock cart; chemical spray by hand compression sprayer; harvesting by improved sickle; threshing by manual pedal thresher; transportation by bullock trolley
Mechanized farm	Power Tiller/ Tractor - Cultivator (2) + Disc harrow (2); sowing with PT seed cum fertilizer drill / Tractor drawn seed cum fertilizer drill; weeding with single row power weeder + manual weeding; manual fertilizer application; chemical spray by power sprayer; harvesting by reaper and threshing by power operated drummy thresher/harvesting by combine harvester; transportation by tractor trolley

Table 12. Improved cultivation practices for transplanting cultivation for optimal energy use

Type of Farm	Package of practices
Animal Farm	Bullock ploughing (M B Plough) x 1 + Bullock disc puddler x 3; mat type nursery preparation; transplanting by manual transplanter; weeding chemical + mechanical + manual; FYM application by bullock cart; chemical spray by hand compression sprayer; harvesting by improved sickle; threshing by manual pedal thresher; transportation by bullock trolley
Mechanized farm	Power Tiller/ Tractor - Cultivator (2) + Disc harrow (2); mat type nursery preparation; transplanting by power transplanter; weeding with two row power weeder + manual weeding; manual fertilizer application; chemical spray by power sprayer; harvesting by reaper and threshing by power operated drummy thresher/harvesting by combine harvester; transportation by tractor trolley

Table 13. Improved cultivation practices for WDSR cultivation for optimal energy use

Type of Farm	Package of practices
Animal Farm	Bullock ploughing (M B Plough) x 1 + Bullock disc puddler x 3; sowing by Manual drawn six row cylindrical drum seeder; weeding chemical + mechanical + manual; FYM application by bullock cart; chemical spray by hand compression sprayer; harvesting by improved sickle; threshing by manual pedal thresher; transportation by bullock trolley
Mechanized farm	Power Tiller/ Tractor - Cultivator (2) + Disc harrow (2); sowing with eight row cup type power seeder; weeding with two row power weeder + manual weeding; manual fertilizer application; chemical spray by power sprayer; harvesting by reaper and threshing by power operated drummy thresher/harvesting by combine harvester; transportation by tractor trolley

9. Input-output energy analysis for rice cultivation methods

Energy studies on rice cultivation under three methods DDSR, WDSR, and transplanting were conducted at NRRI research farm during *kharif* seasons of 2015-2017. All the field preparation operations were conducted by tractor drawn implements. For primary tillage ploughing with MB plough followed by two pass of cultivator for DDSR and one pass of MB plough followed by three passes of disc puddler for WDSR and transplanting. Tractor drawn seed cum fertilizer drill was used for DDSR while self-propelled seeder was used for WDSR and mechanical 8-row transplanter was used for transplanting. For weeding, single row power weeder was used in DDSR while two row self-propelled weeder was used for WDSR and transplanting. All subsequent farm operation (manual fertilizer application, harvesting by self-propelled reaper and threshing by power operated drummy thresher) were similar for all three methods of rice cultivation (plate 11). Naveen was the test variety in experiment. Analysis of overall energy input-outputs were presented in Fig. 11 & 12.

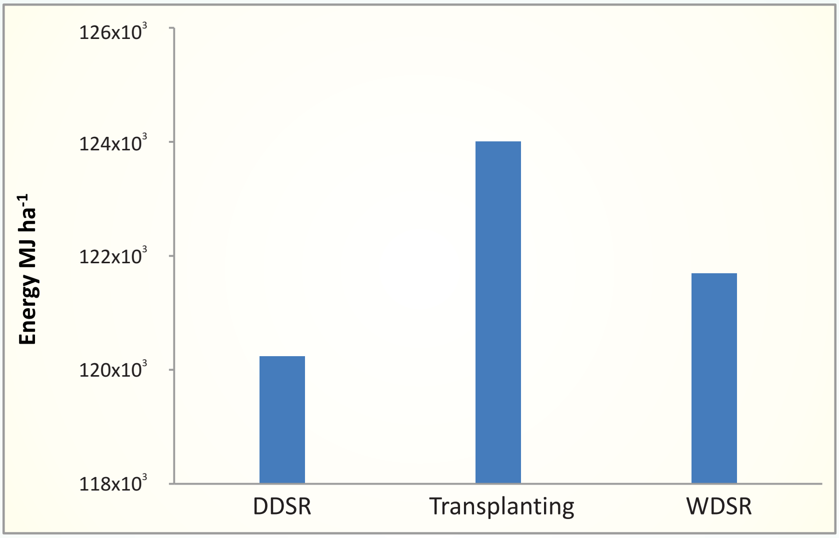


Fig. 11. Net energy gain in rice cultivation methods

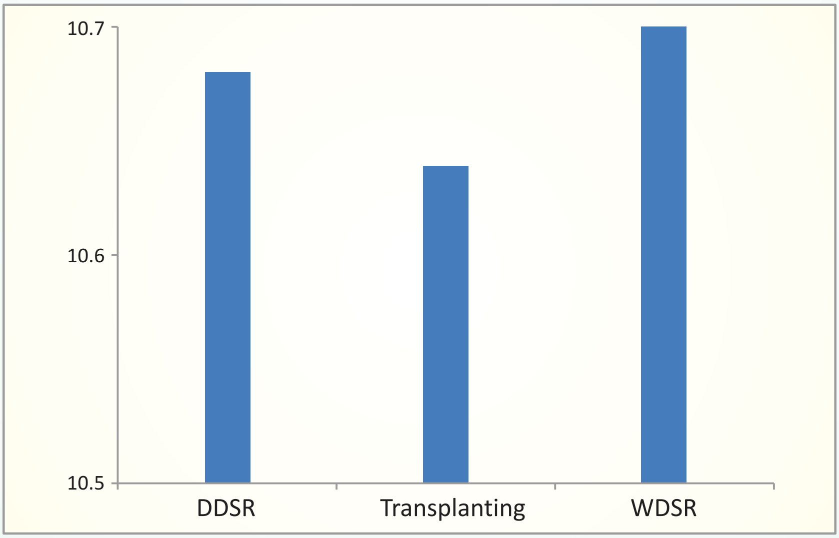


Fig. 12. Energy profitability in rice cultivation methods

Plate 11. Sowing/planting under different establishment methods
(a) dry direct sowing (b) transplanting (c) wet direct sowing used in the experiment

10. Input-output energy analysis of rice cultivars

Field experiments were conducted at the National Rice Research Institute, Cuttack during the years 2012–2013 and 2013–2014. In *kharif* season crops received 1410 mm of rainfall during 2012–2013 and 1757 mm in 2013–2014. To study the varietal difference of rice on energy, three cultivars of rice (Naveen, Swarna and Gayatri) with different durations of 120, 145 and 160 days, respectively, were transplanted during the first week of August. The field was prepared with a tractor-drawn plough followed by puddling and laddering for transplanting. Rainfall was sufficient to fulfil the water needs in the *kharif* season, therefore, no irrigation was applied. Net energy gain and energy profitability for Swarna was found 149395 MJ ha^{-1} and 12.96, respectively, which was highest among three rice cultivars (Fig. 13 & 14).

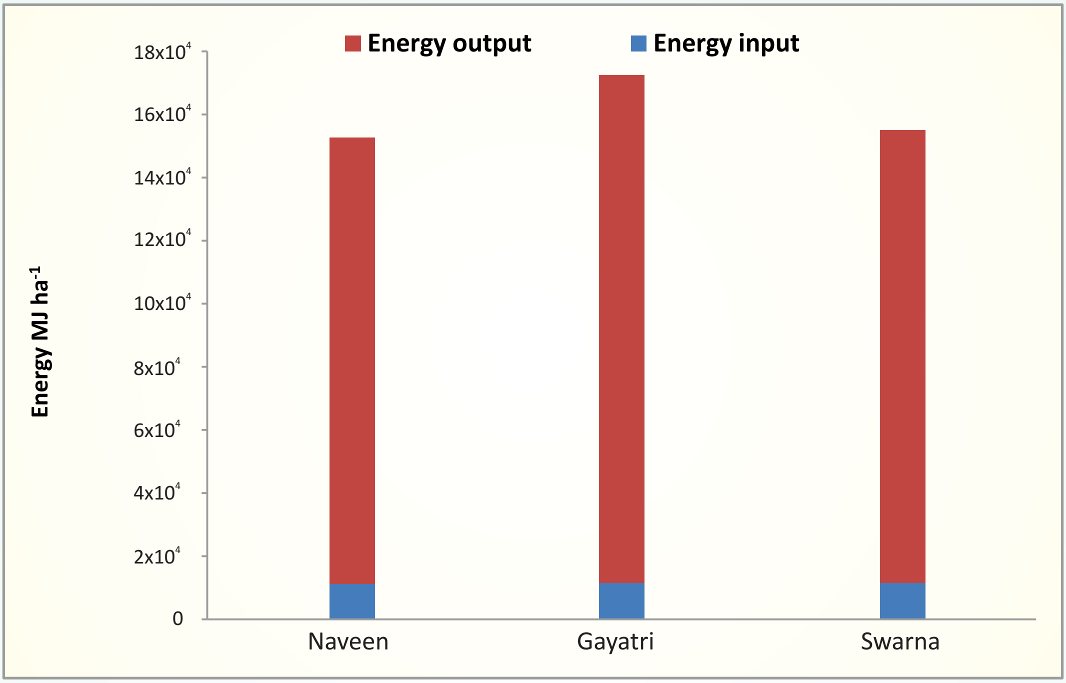


Fig. 13. Energy input-output of different rice varities

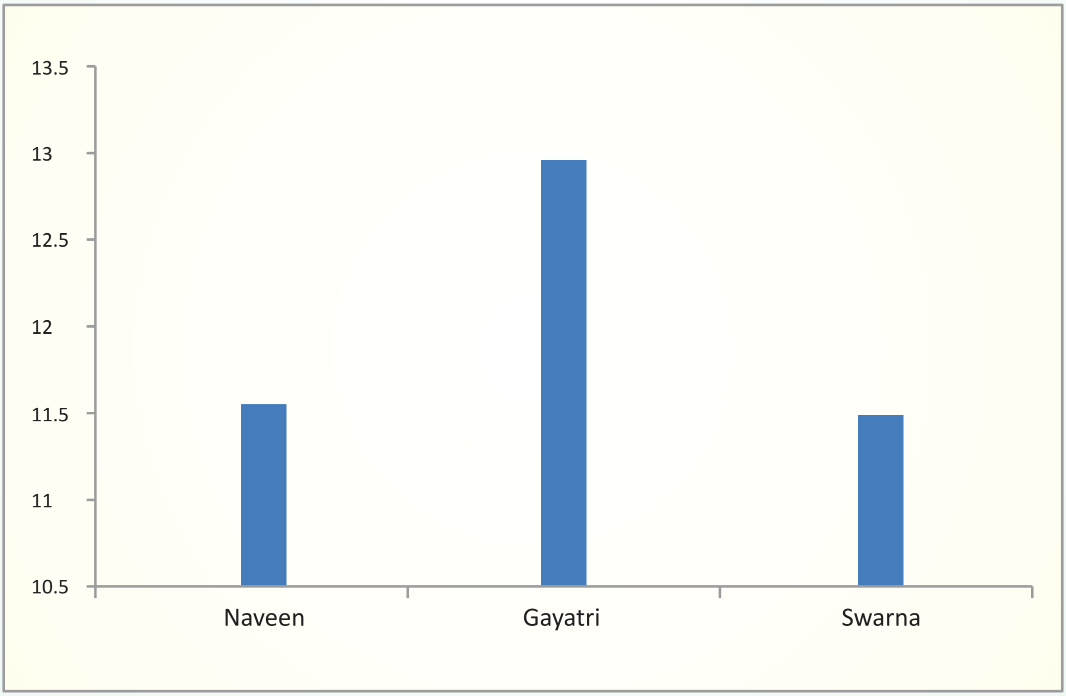


Fig. 14. Energy profitability of different rice varities

Conclusion

In rice production, energy efficiencies differs where mechanization replaces manual labour. The scarcity and high wages of farm labour necessitates mechanized farm at present. The prevailing fragmented and small land holdings create a constraint to the adoption of mechanization. As the use of high capacity mechanized implements on large sized farms has the capacity to enhance the energy use efficiency, hence consolidation of small farms is the need of the hour. More emphasis should be given on energy-efficient rice production system. This research bulletin concludes that method of rice cultivation as well as selection of implements for different field operations has a significant role in energy consumption of rice production. By selection of energy efficient matching implements with tractor, power tiller and bullock, significant amount of energy can be saved. In the anticipated fossil fuel crisis more emphasis should be given to farmer's friendly renewable energy based machinery. With declination in cost of solar panels with higher efficiency, solar energy operated farm equipment can be a good option for elimination fossil fuel based farm equipment.

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