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Energy Dynamics of Rice Production in Eastern India as Influenced by Resource Conserving Establishment Methods and Weed Management

Shivasankar Acharya, S. N. Jena, R. K. Paikaray, B. S. Rath, L. M. Garnayak, S. K. Dwibedi and B. K. Mohapatra

Dept. of Agronomy, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha (751 003), India

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Corresponding acharya.ss@rediffmail.com

0000-0002-4061-4504

ABSTRACT

The field experiment was conducted during the wet seasons of 2020 and 2021, at the Agronomy Research Farm of Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India to assess the input energy requirements and output energy production of establishment methods and weed management in rice. The treatments included three establishment methods viz., Dry-direct seeded rice (Dry-DSR), Wet-DSR and puddled transplanted rice (PTR) in main plot and six weed management treatments viz., hand weeding, oxadiargyl @ 90 g ha^{-1} as pre-emergence (PE) followed by (*fb.*) penoxsulam+cyhalofop @ 135 g ha^{-1} as post-emergence (PoE), oxadiargyl @ 90 g ha^{-1} (PE) *fb.* triafamone+ethoxysulfuron @ 60 g ha^{-1} (PoE), oxadiargyl @ 90 g ha^{-1} (PE) *fb.* bispyribac sodium @ 25 g ha^{-1}+fenoxaprop @ 56 g ha^{-1} (PoE), brown manuring (DSR) / green manuring (PTR) *fb.* 2,4-D at 25 DAS/T and unweeded control in subplot. Dry-DSR utilised 3.2% less input energy than Wet-DSR. PTR recorded highest energy use efficiency (11.88), energy efficiency ratio (5.78), energy productivity (0.393 kg MJ^{-1}) and energy profitability (10.88), followed by Dry-DSR and Wet-DSR. The highest specific energy (4.59 MJ kg^{-1}) was estimated in Dry-DSR, differing significantly with other establishment techniques. Among weed management options, the highest energy use efficiency (11.89) and energy profitability (10.89) was recorded with application of oxadiargyl (PE) *fb.* penoxsulam+cyhalofop (PoE), being at par with hand weeding, oxadiargyl (PE) *fb.* bispyribac sodium+fenoxaprop (PoE). Oxadiargyl *fb.* penoxsulam+cyhalofop under Dry-DSR was highly economic energy efficient, but at par with oxadiargyl *fb.* bispyribac+fenoxaprop under the same establishment technique.

KEYWORDS: Energy use efficiency, penoxsulam+cyhalofop, rice establishment, weed management

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1. INTRODUCTION

Rice production in Asia is the key for global food security, as about 90% of the world rice is produced and consumed in Asia (Bandumula, 2017). India is the second largest producer of rice (118.87 mt), from an area of 43.66 mha, with a productivity of 2.72 t ha^{-1} (Anonymous, 2021). As a major part of Eastern India receives an appreciable amount (1000–1500 mm) of rainfall (Pathak et al., 2020), it has favorable conditions for rice production, to meet the increasing demand. Agriculture is both an energy user and energy supplier in the form of bio-energy. It requires energy as an essential input for crop production (Lal et al., 2013), enhancing food security and adding value (Karimi et al., 2008). Continuously rising prices, increasing proportion of commercial energy in the form of seed, diesel, electricity, fertilizer, plant protection chemicals, irrigation water, machinery, etc. (Iqbal, 2007) and the growing scarcity of energy sources, such as fossil fuels, have necessitated more efficient use of the inputs for different crops.

Rice cultivation is in crisis all over the world and India with shrinking area, reduced water availability, escalating input cost, fluctuating production and stagnating yields (Thakur et al., 2016, Jat et al., 2020). The traditional method of rice growing by transplanting in puddled field is water-capital- and energy-intensive, besides deteriorating the soil health, adversely affecting soil physical properties, which can negatively affect the succeeding non-rice crop in rotation (Tripathi et al., 2005). Transplanting of rice needs 240–250 man-h ha^{-1}, which is 25% of the total labor requirement for rice crop cultivation (Ojha and Kwatra, 2014). The high labour demand at the time of transplanting and rising labour scarcity and wages necessitates exploring resource conserving and energy efficient establishment options in irrigated rice-based systems of eastern India. Direct-seeded rice (DSR) is emerging as a profitable and resource conserving rice production system to address the scarcity of fresh water, labour and energy in agriculture sector (Singh et al., 2016, Kaur and Singh, 2017), that uses pre-monsoon rainfall more efficiently for crop establishment and matures 7–10 days earlier, due to absence of transplanting shock and reduces input cost and irrigation water requirement (Humphreys et al., 2005, Chauhan et al., 2014, Marasini et al., 2016). Wet-DSR, in which sprouted seeds are sown in lines on puddled soil, have also the potential to reduce water requirement compared to puddle transplanted rice (PTR) (Rao et al., 2007, Kumar and Ladha, 2011, Rao et al., 2017). Tillage, irrigation, and fertilization are the primary consumers of energy and contributors of greenhouse gas (GHG) emissions because these farm operations use fossil fuel and electricity (Pratibha et al., 2015, Soni et al., 2013). Hence, in addition to lowering GHG emissions and resilience to climatic variations, DSR provides energy-saving opportunities and better soil physical conditions for the next crop (Ladha et al., 2016, Chakraborty et al., 2017). Despite these benefits, however, the economic benefit from DSR is not realized due to poor crop establishment and severe infestation of weeds (Saha et al., 2021), being the major constraints in the wider scale adoption of DSR (Rao et al., 2017). Further, economical and sustainable weed management strategies under water saving rice production systems are lacking.

Energy use efficiency, net energy and monetary return of a crop are the most important indicators of crop performance, which are necessary for sound planning of sustainable systems and efficient use of scare resources for higher production and productivity (Lal et al., 2015). Therefore, the objective of this study was to identify energy-efficient establishment and weed management technology with satisfactory productivity and energy profitability in rice.

2. MATERIALS AND METHODS

2.1. *Site and climate*

The field experiment was conducted during the wet seasons (June–November) of 2020 and 2021, at the Agronomy Research Farm of Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, Eastern India, which lies at 20°15'N latitude and 85°48'E longitude with an altitude of 25.9 m above the mean sea level. The region is characterized by a subtropical climate with average annual rainfall of 1444 mm (Anonymous, 2021). During rice growing season of 2020, the monthly mean maximum temperature ranged from 31.4°C in the month of November, 2020 to 34.0°C in the month of June, 2020, whereas, the monthly mean minimum temperature ranged from 26.7°C in the month of June, 2020 to 19.6°C in the month of November, 2020. During rice growing season of 2021, the monthly mean maximum temperature ranged from 34.0°C in the month of June, 2021 to 30.2°C, in November, 2021, whereas, the monthly mean minimum temperature ranged from 21.8°C in the month of November, 2021 to 26.3°C in the month of June, 2021. The crop received 1237 mm of rainfall during 2020 and 1395 mm in 2021. The soil was sandy loam texture (72.6% sand, 12.2% silt and 15.2% clay), with acidic pH (5.42), low available N (213.2 kg ha^{-1}), medium P (21.7 kg ha^{-1}) and K (148.4 kg ha^{-1}).

2.2. *Experimental design*

The experiment was laid out in a split plot design with three replications by taking three establishment methods viz. Dry-DSR, Wet-DSR and PTR in the main plot and six weed management practices in rice viz., hand weeding twice at 20 and 40 days after sowing/transplanting (DAS/T), oxadiargyl @ 90 g ha^{-1} as pre-emergence (PE) followed by (*fb.*) penoxsulam+cyhalofop @ 135 g ha^{-1}as post-emergence (PoE), oxadiargyl @ 90 g ha^{-1} (PE) *fb.* triafamone+ ethoxysulfuron @ 60 g ha^{-1} (PoE), oxadiargyl @ 90 g ha^{-1} (PE) *fb.* bispyribac sodium @ 25 g ha^{-1}+fenoxaprop @ 56 g ha^{-1} (PoE), living mulch as brown manuring (DSR) / green manuring (PTR) with 2, 4-D at 25 DAS/T and unweeded control the sub-plots. The pre-emergence herbicide was applied two DAS/T in Dry-DSR and PTR, whereas, it was applied at four DAS in Wet-DSR. The post-emergence herbicides were applied at 20 DAS/T. All the herbicides were applied through Knapsack sprayer using 500 L water ha^{-1}.

2.3. *Crop management practices*

The Dry-DSR field was initially dry ploughed with2 discings and 2 harrowings followed by levelling for sowing. The sowing under Dry-DSR was done with seed drill with a seed rate of 50 kg ha^{-1} at a row-spacing of 20 cm. For preparing the field under Wet-DSR, 2 discings and 2 harrowings were done under aerobic soil conditions and then the land was puddled and levelled. Pre-germinated seeds, prepared by soaking and incubating for 24 h each, were sown on the surface of the drained puddled soil by using a drum seeder. For PTR, 2 discings and 2 harrowings were done under aerobic soil conditions, and then soil was puddled with water for easy transplanting of rice seedlings in soft mud of the field. Wet nursery was prepared to raise the seedling for use in main experiment at a seed rate of 40 kg ha^{-1} for puddled transplanting. Rice variety 'Hasanta', having maturity duration of 145 days was used for the investigation.

At the time of final ploughing, FYM @ 5 t ha^{-1} was incorporated into the soil. Inorganic fertilizers @ 80-40-40 kg N-P_2O_5-K_2O ha^{-1} were applied to all the plots irrespective of treatments. Full doses of P_2O_5 and K_2O along with 25% of N were applied as basal, whereas, rest of N was applied in 2:1 ratio at tillering and panicle initiation stage of rice. For Dry-DSR, dry rice seeds were sown in line on 26th June, 2020 in first year and the same week (26th week) was maintained in second year for sowing and were sown on 30th June, 2021. For preparing pre-germinated seeds to be used in Wet-DSR and PTR, dry seeds were soaked in water on the same date of sowing of Dry-DSR of respective years, for 24 h, followed by incubation for 24 h. For Wet-DSR, the pre-germinated seeds were sown on 29th June, 2020, in first year and 3rd July, 2021 in second year, whereas, for PTR, the same pre-germinated seeds were used for nursery raising and 21 days seedlings were used for transplanting. Weed management operations were performed as per the treatment specifications. *Methods of energy budgeting*

The energy performance of the crop establishment and weed management methods were assessed according to different input intensities. Energy fluxes were estimated using crop management and grain production along with by-products. Inputs and outputs were converted from physical to energy unit measures through published conversion coefficients given in Table 1 (Singh et al., 2008, Devasenapathy et al., 2009).

Table 1: Energy equivalents of inputs and outputs in agricultural production

Components (unit)	Energy equivalent (MJ $unit^{-1}$)
Input	
Labor (h)	1.96
Machinery (h)	62.7
Diesel (l)	56.31
Seed (kg)	14.7
Chemical fertilizers (kg)	
N	60.6
P_2O_5	11.1
K_2O	6.7
Herbicide (kg)	288
Pesticide (kg)	120
Irrigation (m^3)	1.02
Output (kg)	
Grain	14.7
Straw	12.5

Energy equivalents for all inputs were summed to provide an estimate of total energy inputs. Energy output from the grain yield and straw yield was calculated by multiplying the amount of production by its corresponding energy equivalent. On the basis of energy input and output, net energy returns, energy use efficiency, energy efficiency ratio, specific energy, energy productivity and energy profitability were calculated by using the following formulae, as suggested by Mittal and Dhawan (1988) and Burnett (1978).

Net energy return=Total Output Energy (MJ ha^{-1})-Total Input Energy (MJ ha^{-1})…….(1)

Energy use efficiency =Total Output Energy (MJ ha^{-1})/Total Input Energy (MJ ha^{-1})……………….(2)

Energy efficiency ratio=Total Output Energy in main product (MJ ha^{-1})/(Total Input Energy (MJ ha^{-1}) …….(3)

Specific Energy = Total Input Energy (MJ ha^{-1})/Total main product yield (kg ha^{-1})……………………(4)

Energy productivity = Total main product yield (kg ha^{-1})/ Total Input Energy (MJ ha^{-1}) ………………..(5)

Energy profitability = Net energy return (MJ ha^{-1})/Total Input Energy (MJ ha^{-1})………………..(6)

Economic energy efficiency = Total Energy output (MJ ha^{-1})/Cost of cultivation (Rs. ha^{-1})…………………..(7)

2.4. Statistical analysis

The data of 2 years for different energy indices were calculated and pooled analysis was done using standard procedures of variance analysis and the significance of different source of variations was tested at 5% level of significance.

3. RESULTS AND DISCUSSION

3.1. Analysis of input energy use in rice production

The input energy requirement for rice for various farm operations excluding weed management under various establishment techniques, viz., Dry-DSR, Wet-DSR and PTR were 11712, 12133 and 11886 MJ ha^{-1} respectively (Table 2). Dry-DSR utilised 3.2% less input energy than Wet-DSR, due to lesser energy requirement for land preparation, whereas, Wet-DSR utilized the highest amount of energy because of higher input energy for puddling and utilisation of drum seeder for sowing. Among various farm operations and inputs, manures and fertilizers registered the highest percentage of total input energy followed by land preparation, which was in conformity with the findings of Tuti et al. (2012). On an average, manures and fertilizer consumed 60.82, 58.71 and 59.93% of total energy inputs for Dry-DSR, Wet-DSR and PTR, respectively. Energy requirement for manual hand weeding was highest in Dry-DSR (706 MJ ha^{-1}) as compared to PTR (392 MJ ha^{-1}). The higher amount of input energy under Dry-DSR was due to more number of mandays requirements than Wet-DSR and PTR.

Table 2: Operation wise input energy values of establishment methods of rice (excluding weed management)

Operations	Dry-DSR		Wet-DSR		PTR	
	Energy (MJ ha^{-1})	Percentage of total energy input (%)	Energy (MJ ha^{-1})	Percentage of total energy input (%)	Energy (MJ ha^{-1})	Percentage of total energy input (%)
Land Preparation	1339	11.43	1760	14.51	1820	15.31
Seed	735	6.28	735	6.06	588	4.95
Sowing/Transplanting	662	5.65	662	5.46	502	4.22
Manure and Fertilizer	7123	60.82	7123	58.71	7123	59.93
Harvesting	759	6.48	759	6.26	759	6.39
Threshing	687	5.87	687	5.66	687	5.78
Pesticide	407	3.48	407	3.35	407	3.42
Total	11712		12133		11886	

With the inclusion of manual weed management through hand weeding, total energies used during rice production were 12418, 12681 and 12278 MJ ha^{-1} under Dry-DSR, Wet-DSR and PTR, respectively (Table 3). Weed management through herbicides reduced the input energy requirement compared to hand weeding, with the lowest input energy use estimated was 75 MJ ha^{-1}, when applied with oxadiargyl @ 90 g ha^{-1} (PE) *fb.* triafamone+ ethoxysulfuron @ 60 g ha^{-1} (PoE). Considering all the weed management treatments taken in the experiment, Dry-DSR recorded the lowest input energy (11901 MJ ha^{-1}), followed by PTR (12022 MJ ha^{-1}) and Wet-DSR (12295 MJ ha^{-1}). Among the weed management treatments, hand weeding twice resulted in higher input energy use (12459 MJ ha^{-1}), followed by brown/green manuring (12086 MJ ha^{-1}), oxadiargyl @ 90 g ha^{-1} (PE) *fb.* penoxsulam+cyhalofop @ 135 g ha^{-1} (PoE) (12006 MJ ha^{-1}).

3.2. Energy input–output relationship

Based on pooled data of main (grain) and by-product (straw) yield, all the establishment techniques produced more output energy than that required for the crop production, resulting in positive net energy returns (Table 4). The highest output energy (142888 MJ ha^{-1}) was estimated for PTR, which was 23.6 and 20.3% higher than Dry-DSR and Wet-DSR, respectively, but the latter two were at par with each other.

Among the weed management treatments, the highest output energy was registered under hand weeding twice (147863 MJ ha^{-1}) due to manual elimination of weeds under various establishment options, producing higher main and by-product yields in rice. With respect to herbicidal weed management options, application of oxadiargyl @ 90 g ha^{-1} (PE) *fb.* penoxsulam+cyhalofop @ 135 g ha^{-1} (PoE) produced highest output energy (142655 MJ ha^{-1}) which was at par with hand weeding twice and oxadiargyl @ 90 g ha^{-1} (PE) *fb.* Bispyribac Sodium @ 25 g ha^{-1}+Fenoxaprop @ 56 g ha^{-1} (PoE) with energy output of 137926 MJ ha^{-1}. Higher output energy production in oxadiargyl @ 90 g

Table 3: Input energy values of weed management treatments under establishment methods

Treatments	Dry-DSR			Wet-DSR			PTR		
	Fixed input energy (MJ ha^{-1})	Variable input Energy (MJ ha^{-1})	Total Energy	Fixed input energy (MJ ha^{-1})	Variable input Energy (MJ ha^{-1})	Total Energy	Fixed input energy (MJ ha^{-1})	Variable input Energy (MJ ha^{-1})	Total Energy
Hand weeding twice at 20 and 40 DAS/T	11712	706	12418	12133	549	12681	11886	392	12278
Oxadiargyl @ 90 g ha^{-1} (PE) fb. Penoxsulam+ Cyhalofop @ 135 g ha^{-1} (PoE)	11712	96	11808	12133	96	12229	11886	96	11982
Oxadiargyl @ 90 g ha^{-1} (PE) fb. Triafamone+ Ethoxysulfuron @ 60 g ha^{-1} (PoE)	11712	75	11787	12133	75	12207	11886	75	11961
Oxadiargyl @ 90 g ha^{-1} (PE) fb. Bispyribac Sodium @ 25 g ha^{-1}+ Fenoxaprop @ 56 g ha^{-1} (PoE)	11712	81	11793	12133	81	12213	11886	81	11967
Brown/Green Manuring fb. 2,4-D	11712	175	11888	12133	175	12308	11886	175	12061
Unweeded control	11712	0	11712	12133	0	12133	11886	0	11886

ha^{-1} (PE) *fb.* penoxsulam+cyhalofop @ 135 g ha^{-1} (PoE) was due to the effective suppression of germinating weeds after sowing by oxadiargyl and subsequent post-emergent application of penoxsulam+cyhalofop, controlling broad spectrum of weeds by inhibiting acetolactate synthase enzyme, responsible for the synthesis of amino acids in weeds, thereby enhancing higher output energy. Effective weed control increased the grain and straw yields in rice enhancing the output energy. Lowest output energy (76971 MJ ha^{-1}) was recorded with unweeded control treatment, because of significant reduction of both the main and by-product yield of rice in the experiment.

Among establishment options, the highest net energy return (130865 MJ ha^{-1}) was recorded in PTR, followed by Wet-DSR (106508 MJ ha^{-1}) and Dry-DSR (103736 MJ ha^{-1}), which was due to higher production of output energy by PTR. Though hand weeding resulted in the highest net energy return (135404 MJ ha^{-1}), it was at par with application of oxadiargyl @ 90 g ha^{-1} (PE) *fb.* penoxsulam+cyhalofop @ 135 g ha^{-1} (PoE) (130649 MJ ha^{-1}), oxadiargyl @ 90 g ha^{-1} (PE) *fb.* bispyribac sodium @ 25 g ha^{-1}+fenoxaprop @ 56 g ha^{-1} (PoE) (125929 MJ ha^{-1}) and oxadiargyl @ 90 g ha^{-1} (PE) *fb.* triafamone+ethoxysulfuron @ 60 g ha^{-1} (PoE) (122875 MJ ha^{-1}).

3.3. *Energy indices as influenced by establishment techniques and weed management*

PTR recorded the highest energy use efficiency (11.88), energy efficiency ratio (5.78), energy productivity (0.393 kg MJ^{-1}) and energy profitability (10.88 MJ MJ^{-1}), followed by Dry-DSR and Wet-DSR (Table 5), the latter two being at par. Higher value of energy efficiency of PTR was due to lesser crop-weed competition and higher production ability of the establishment technique. The higher crop-weed competition in DSR reduced the output energy that resulted in lower energy use efficiency, efficiency ratio, energy productivity and energy profitability than PTR. The highest specific energy (4.59 MJ kg^{-1}) was estimated in Dry-DSR, differing significantly from all other establishment techniques, due to comparatively higher energy requirement for unit main product yield.

Among the weed management options, the highest energy use efficiency (11.89) and energy profitability (10.89) were recorded with application of oxadiargyl @ 90 g ha^{-1} (PE) *fb.* penoxsulam+cyhalofop @ 135 g ha^{-1} (PoE), being at par with hand weeding twice, Oxadiargyl @ 90 g ha^{-1} (PE) *fb.* bispyribac sodium @ 25 g ha^{-1}+fenoxaprop @ 56 g ha^{-1} (PoE) and oxadiargyl @ 90 g ha^{-1} (PE) *fb.* triafamone+ethoxysulfuron @ 60 g ha^{-1} (PoE). This

Table 4: Effect of crop establishment techniques and weed management on energetics of rice

Treatments	Energy input (MJ ha^{-1})	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Energy output (MJ ha^{-1})	Net energy return (MJ ha^{-1})
Establishment methods					
Dry- DSR	11901	3818	4762	115637	103736
Wet-DSR	12295	3890	4930	118803	106508
PTR	12022	4731	5867	142888	130865
SEm±	-	76.8	122.4	2060	2060
CD (p=0.05)	-	250.3	399.1	6716	6716
Weed management					
Hand weeding twice at 20 and 40 DAS/T	12459	5039	5903	147863	135404
Oxadiargyl @ 90 g ha^{-1} (PE) fb. Penoxsulam+Cyhalofop @ 135 g ha^{-1} (PoE)	12006	4807	5759	142655	130649
Oxadiargyl @ 90 g ha^{-1} (PE) fb. Triafamone+Ethoxysulfuron @ 60 g ha^{-1} (PoE)	11985	4393	5623	134860	122875
Oxadiargyl @ 90 g ha^{-1} (PE) fb. Bispyribac Sodium @ 25 g ha^{-1}+Fenoxaprop @ 56 g ha^{-1} (PoE)	11991	4572	5658	137920	125929
Brown/Green manuring fb. 2,4-D	12086	3712	4786	114387	102301
Unweeded control	11910	2355	3388	76971	65061
SEm±	-	145.9	186.1	4454	4450
CD (p=0.05)	-	412.6	526.3	12599	12586
Establishment method×Weed management					
SEm±	-	206.3	263.1	6299	6293
CD (p=0.05)	-	583.5	744.3	17817	17799

Table 5: Energy indices as influenced by establishment techniques and weed management

Treatments	Energy use efficiency	Energy efficiency ratio	Specific energy (MJ kg^{-1})	Energy productivity (kg MJ^{-1})	Energy Profitability (MJ MJ^{-1})
Establishment methods					
Dry- DSR	9.69	4.70	4.59	0.320	8.69
Wet-DSR	9.65	4.64	3.42	0.316	8.65
PTR	11.88	5.78	2.58	0.393	10.88
SEm±	0.17	0.09	0.07	0.006	0.17
CD (p=0.05)	0.55	0.31	0.22	0.021	0.55
Weed management					
Hand weeding twice at 20 and 40 DAS/T	11.87	5.95	2.49	0.405	10.87
Oxadiargyl @ 90 g ha^{-1} (PE) *fb.* Penoxsulam+Cyhalofop @ 135 g ha^{-1} (PoE)	11.89	5.89	2.53	0.401	10.89
Oxadiargyl @ 90 g ha^{-1} (PE) fb. Triafamone +Ethoxysulfuron @ 60 g ha^{-1} (PoE)	11.26	5.39	2.76	0.367	10.26
Oxadiargyl @ 90 g ha^{-1} (PE) *fb.* Bispyribac Sodium @ 25 g ha^{-1}+Fenoxaprop @ 56 g ha^{-1} (PoE)	11.51	5.61	2.66	0.382	10.51

Table 5: Continue...

Treatments	Energy use efficiency	Energy efficiency ratio	Specific energy (MJ kg^{-1})	Energy productivity (kg MJ^{-1})	Energy Profitability (MJ MJ^{-1})
Brown/Green manuring fb. 2,4-D	9.46	4.51	3.39	0.307	8.46
Unweeded control	6.45	2.90	7.35	0.197	5.45
SEm±	0.38	0.18	0.51	0.012	0.38
CD (*p*=0.05)	1.07	0.51	1.45	0.035	1.07
Establishment method×Weed management					
SEm±	0.53	0.26	0.73	0.017	0.53
CD (*p*=0.05)	1.51	0.73	2.05	0.049	1.51

might be due to production of higher output energy with lesser utilization of input energy with the said herbicide treatments. Hand weeding twice resulted in the highest energy efficiency ratio (5.95), energy productivity (0.405 kg MJ^{-1}) but the lowest specific energy (2.49), being closely followed by application of oxadiargyl @ 90 g ha^{-1} (PE) *fb.* penoxsulam+cyhalofop @ 135 g ha^{-1} (PoE) and oxadiargyl @ 90 g ha^{-1} (PE) *fb.* bispyribac Sodium @ 25 g ha^{-1}+Fenoxaprop @ 56 g ha^{-1} (PoE), which might be due to effective control of weeds, thereby reducing the crop weed competition and enhancing the output energy in the form of grain and straw yield of rice. These results are in harmony with the findings of Singh et al. (2016), Yogananda et al. (2017) and Lal et al. (2016).

The pooled data of economic energy efficiency in rice as influenced by interaction effect of establishment techniques and weed management practices (Table 6) revealed application of oxadiargyl *fb.* penoxsulam+cyhalofop under Dry-DSR was highly economic energy efficient with value of 2.92 MJ ₹$^{-1}$, being at par with oxadiargyl *fb.* bispyribac+fenoxaprop under the same establishment technique (2.78 MJ ₹$^{-1}$).

Table 6: Economic energy efficiency (MJ ₹$^{-1}$) in rice as influenced by interaction effect of establishment techniques and weed management (Pooled data of 2 years)

Treatments	W_1	W_2	W_3	W_4	W_5	W_6	Mean
M1: Dry-DSR	2.45	2.92	2.73	2.78	1.95	0.71	2.26
M2: Wet-DSR	2.56	2.59	2.37	2.40	2.22	1.56	2.29
M3: PTR	2.27	2.41	2.28	2.33	2.34	2.16	2.30
Mean	2.43	2.64	2.46	2.51	2.17	1.48	
	M	W	M within W	W within M			
SEm±	0.04	0.09	0.12	0.13			
CD (p=0.05)	NS	0.26	0.34	0.37			

W_1: HW twice; W_2: Oxadiargyl fb. Penoxsulam +Cyhalofop; W_3: Oxadiargyl fb. Triafamone+Ethoxysulfuron; W_4: Oxadiargyl fb. Bispyribac+Fenoxaprop; W_5: Brown/Green Manuring fb. 2,4-D; W_6: Unweeded control

4. CONCLUSION

Herbicide technology offered an alternative method of selective and economical control of weeds with lesser input energy in rice. Though the highest grain and straw yield was obtained with PTR, it resulted in lowest specific energy. Pre-emergence application of oxadiargyl @ 90 g ha^{-1} followed by penoxsulam+cyhalofop @ 135 g ha^{-1} as post-emergence is the suitable herbicide combination for economically energy efficient weed management strategy in dry direct seeded and puddled transplanted rice cultivation in Eastern India.

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