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Nisha Verma
M. Tech, Department of Farm Machinery and Power Engineering, SVCAET & RS, FAE, IGKV, Raipur, Chhattisgarh, India

AK Dave
Professor, Department of Farm Machinery and Power Engineering, SVCAET & RS, FAE, IGKV, Raipur, Chhattisgarh, India

Nihal Kumar Pandey
M. Tech, Department of Farm Machinery and Power Engineering, SVCAET & RS, FAE, IGKV, Raipur, Chhattisgarh, India

AK Shrivastava
Assistant Professor, Department of Farm Machinery and Power Engineering, KDCCARS, IGKV, Raipur, Chhattisgarh, India

Corresponding Author:
Nisha Verma
M. Tech, Department of Farm Machinery and Power Engineering, SVCAET & RS, FAE, IGKV, Raipur, Chhattisgarh, India

Investigates the impact of level of passes of puddling implements on summer rice yield and energy efficiency

Nisha Verma, AK Dave, Nihal Kumar Pandey and AK Shrivastava

Abstract
Puddling effects were investigated in terms of energy use pattern, puddling index, depth of puddling, regermination of weeds and yield of summer rice cultivation. A study was conducted at agriculture farm of IGKV, Raipur, (Chhattisgarh) India during rabi season of 2022-2023 with nine treatments which were replicated thrice. The energy consumption of the various operations in each treatment has been recorded. Total energy input and output of summer rice were estimated by using the standard energy equivalents. The puddling index, depth of puddling, regermination of weeds varied from 37.73-56.90%, 108-148 mm, 28.16 – 39.16% per m^2, respectively. The highest energy requirement for puddling operation was found 2796.81 MJ/ha for treatment T_8 (Rotavator × 3). The highest input energy requirement for rice cultivation in treatment T_8 (Rotavator × 3) was found to be 25113.39 MJ/ha in which fertilizer consumed almost 46.9% i.e., 7013. 60 MJ ha^{-1} of total energy use. The overall best output was obtained in treatment T_5 (Cultivator × 2 + Rotavator × 2) with a total of 251962 MJ/ha. The results revealed that energy output-input ratio, net energy, energy productivity and specific energy of treatment T_5 (Cultivator × 2 + Rotavator × 2) for summer rice cultivation was found to be 10.13, 227093.63 MJ /ha, 0.310 kg/MJ and 2.53 MJ /kg, respectively.

Keywords: Rice, puddling index, energy ratio, specific energy, yield, productivity

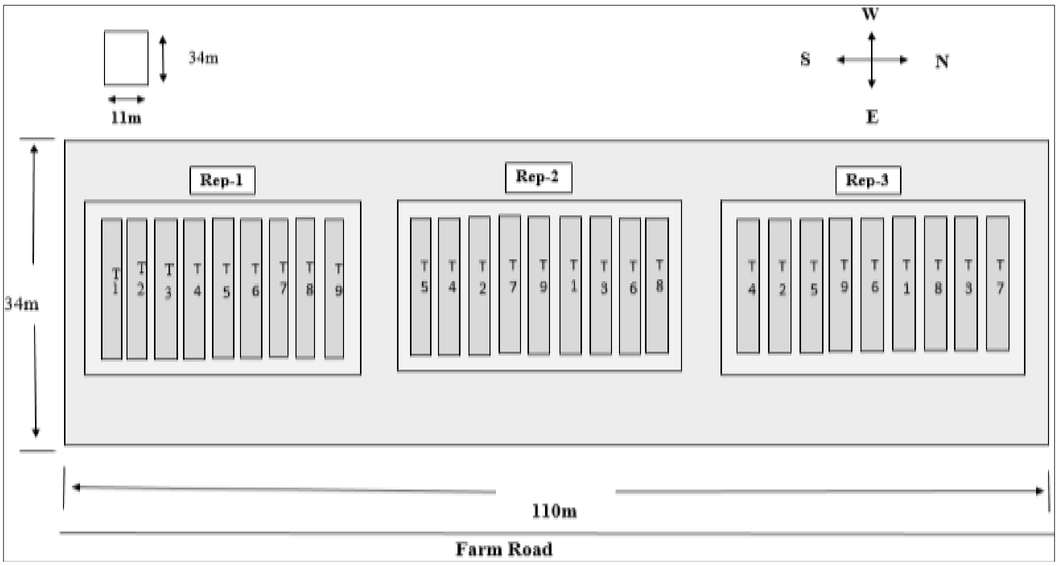
1. Introduction
Rice cultivation is crucial in India, the second-largest producer globally. The rice crop is grown on nearly 45.07 million ha of land in the country, with a production of 122.27 MT and a productivity of 2.7 t/ha (Anon., 2021) [7]. However, India's rice productivity lags due to small land holdings, limited mechanization, and irrigation. Chhattisgarh, known as the "rice bowl," primarily relies on rainfed rice farming, but yields are lower than the national average. In Chhattisgarh, the total area of rice is 3793.19 thousand ha, production is 9103.66 metric tonnes and productivity are 2400 kg/ha in the year of 2022. Chhattisgarh's climate and soil are ideal for rice, farmers in the state have shifted towards cultivating paddy during the dry season, increasing summer paddy cultivation areas.

Efficient tillage practices are essential in rice cultivation to conserve energy and reduce production costs. Excessive tillage consumes more fuel and increases expenses, while strategic minimum tillage can save up to 40% of fuel and improve soil health. Puddling is an essential process in the cultivation of rice, is also an energy-intensive operation which requires a substantial quantity of water. Managing water resources and selecting suitable rice varieties are critical in dry season cultivation. Mechanization not only ensures timely operations, better water and weed management, and increased yields but also attracts labor to non-farm sectors, contributing to rural economic growth.

2. Materials and Methods
The study was conducted at agriculture farm of Indira Gandhi Krishi Vishwavidyalaya, Raipur, India during Rabi season of 2022-2023. The experiment was conducted with nine treatments which were replicated thrice and having total plots size of 110×34 m^2 and 11×34 m^2 for each treatment respectively. The details of experiment, dependent and independent variables are shown in Table 1. And the layout plan is shown in Fig. 1.

Table 1: Dependent and independent variables of experimental study

(A) Independent variables		
S. No.	**Treatment**	**Details of treatment**
1.	T_1	Cultivator × 1 + Rotavator × 1
2.	T_2	Cultivator × 1 + Rotavator × 2
3.	T_3	Cultivator × 1
4.	T_4	Cultivator × 2 + Rotavator × 1
5.	T_5	Cultivator × 2 + Rotavator × 2
6.	T_6	Cultivator × 2
7.	T_7	Rotavator × 2
8.	T_8	Rotavator × 3
9.	T_9	Desi plough × 4 with a pair of bullocks
(B) Dependent variables		
(a)	Soil parameters	
1.	Bulk density, g/cm^3	
2.	Moisture content,%	
3.	Puddling index,%	
4.	Depth of puddling, cm	
5.	Soil inversion, m^{-2}	
(b)	Machine parameters	
1.	Effective field capacity, ha/h	
2.	Field efficiency,%	
3.	Fuel consumption and time requirement, l/h and h/ha	
(c)	Plant growth parameters	
1.	Plant height, cm	
2.	No. of tillers, m^{-2}	
(d)	Yield parameters	
1.	Spike length, cm	
2.	Thousand grain weight, g	
3.	Grain yield, q/ha	
4.	Straw yield, q/ha	



T_1 - Cultivator × 1 + Rotavator × 1; T_2 - Cultivator × 1 + Rotavator × 2; T_3 - Cultivator × 1; T_4 - Cultivator × 2 + Rotavator × 1; T_5 - Cultivator × 2 + Rotavator × 2; T_6 - Cultivator × 2; T_7 - Rotavator × 2; T_8 -Rotavator × 3; T_9 - Desi plough × 4 with a pair of bullocks

Fig 1: Experimental layout

Puddling Index

The performance of puddling implement was evaluated on the basis of puddling index. In order to find out puddling index the samples of the puddled soil were collected randomly from the plot. The samples of 250 cc immediately after puddling were collected by inserting a glass tube to a depth about 10 to 12 cm. puddled samples were allowed to settle for 48 hours in a graduated cylinder. The volume of settled soil sample and clean water were recorded and puddling index is determined by the following formula (Pandey and ojha, 1973) [8].

$$Pl = \frac{Vs}{V} \text{ x } 100$$

Where,
Pl = Puddling index (%)
Vs = Volume of settled soil, cm^3
V = Total volume of sample, cm^3

Depth of Puddling

The depth of puddling was recorded following the standard method suggested (Fig. 2). A scale was inserted just after puddling to record the depth of puddling, the depth of standing water, and the depth of the puddle.

Fig 2: Measurement of depth of puddling

Soil Inversion

As per IS test code (IS: 6288-1971) a square rig (1m x 1m) was placed randomly in the field before ploughing. The numbers of weeds and stables enclosed within the rig were counted. The above process after ploughing the field was recorded, and a calculation of soil inversion was made as follows:

$$\text{Soil inversion} = \frac{(\text{No.of weeds before ploughing} - \text{No.of weeds after ploughing})}{\text{No.of weeds before ploughing}} \times 100$$

To record the effect of puddling on population of weeds per m² similar procedure mentioned above was used. According to that regermination of weeds

After 10 days of puddling was recorded.

$$\text{Regermination of weeds} = \frac{\text{Weeds after 10 days of puddling} - \text{Weeds after puddling}}{\text{Weeds after puddling}} \times 100$$

Calculation of Energy

The energy consumption in different treatment combinations of tillage for summer rice cultivation was calculated operations-wise and sources-wise. The energy for commercial and non-commercial sources (human, animal) was also calculated. The data was collected in field operation and energy use in different operation was calculating by using energy equivalent in Table 2.

Table 2: Energy equivalents of energy sources

Particulars	Units	Equivalent energy, MJ
A. Inputs		
1. Human labour	Man-hour	1.96
2. Woman	Woman-hour	1.57
3. Diesel	litre	56.31
4. Electricity	kWh	11.93
5. Machinery		
a. Electric motor	kg	64.80
b. Prime mover (self-propelled)	kg	68.40
c. Farm machinery	kg	62.70
6. Chemical fertilizers		
Nitrogen	kg	60.60
P_2Os	kg	11.10
K_2O	kg	6.70
B. Output		
1. Main product (Grain	kg (dry mass)	14.70
2. By-product	kg (dry mass)	12.50

The total energy input and output of rice were assessed by applying energy equivalence values recommended by many researchers. The energy input was determined by considering various agricultural activities, such as land preparation, seed bed preparation, seed sowing, transplanting, fertilizer and pesticide application,

Intercultural operations, irrigation, harvesting, threshing, and transportation. The energy output was calculated by accumulating the main product and by-product produced. The net energy return was obtained by subtracting the input energy from the output energy. The output-input ratio was calculated by dividing the total energy generated from both the main product and by-products by the total energy used for raising the crop in the unit area. The energy input and output were computed as Mega Joule (MJ) by following formulae:

Energy Input = $E_{hl} + E_{pr} + E_{mt}$ …… (1)

Where,

E_{hl} = Energy from human labour

E_{pr} = Energy from power

E_{mt} = Energy from materials likes seed, fertilizer, Pesticides and irrigation etc.

Energy output = $E_{mp} + E_{bp}$ …… (2)

Where,

E_{mp} = Energy from main product

E_{bp} = Energy from by-product

The energy ratio, energy productivity, specific energy, and net energy can be calculated using the following formulae:

$$\text{EOIR} = \frac{\text{Total energy output (MJ/ha)}}{\text{Total energy input (MJ/ha)}} \ldots\ldots \quad (3)$$

$$\text{Energy productivity (kg/MJ)} = \frac{\text{Grain yield (kg/ha)}}{\text{Total energy input (MJ/ha)}} \ldots \quad (4)$$

$$\text{Specific energy (MJ/kg)} = \frac{\text{Total energy input (MJ/ha)}}{\text{Grain yield (kg/ha)}} \;\ldots\ldots (5)$$

$$\text{Net energy (MJ/ha)} = \text{Energy output (MJ/ha)} - \text{Energy input (MJ/ha)} \;\ldots\ldots (6)$$

3. Results and Discussions

Effect of puddling-on-puddling index, depth of puddling and soil inversion: It was found that puddling index increase with level of puddling irrespective combination of rotavator and cultivator. There was significant difference in puddling index for treatment T_5, T_4, T_2, and T_8 as compared to T_9. However, test of the treatment at par. The increase in value of puddling index was on higher in case of rotavator and cultivator combination as compared to Desi plough in all combination of puddling treatments. It was found that the highest value of puddling index (56.90%) was observed in treatment T_5, (Cultivator × 2 + Rotavator × 2) and lowest in treatment T_9 (Desi plough × 4 with a pair of bullocks).

Table 3: Effect of puddling-on-puddling index, depth of puddling and regermination of weeds

Treatment	Puddling index (%)	Depth of puddling (mm)	Weeding percentage before puddling (m^{-2})	Regermination percentage of weeds after puddling (m^{-2})
T_1	46.77	121	74.72	29.82
T_2	51.53	139	69.57	28.16
T_3	41.9	118	69.22	35.18
T_4	50.63	122	71.63	37.73
T_5	56.9	148	73.31	31.54
T_6	43.43	125	71.78	38.14
T_7	50	134	70.73	32.47
T_8	53.53	144	69.51	30.21
T_9	37.73	108	67.54	39.16
C.D.	6.831	N/A	2.801	2.23
SE(m)	2.259	0.683	0.926	0.738
SE(d)	3.195	0.966	1.31	1.043

Depth of puddling was found significantly higher in case of treatment T_5 (Cultivator × 2 + Rotavator × 2), 148 mm. Increase in level of puddling from 3 to 4 or 2 to 3 passes of Cultivator and Rotavator combination increased the depth of puddling might be due to progressive increase in softness of the puddled soil with each single operation. The value of depth of puddling among puddling treatments varies from 108 mm to 148 mm. The lowest value of 108 mm was observed under treatment T_9 (Desi plough × 4 with a pair of bullocks). However, the values were from 100 to 150 mm for two to four passes of puddling in any combination.

It was observed that the lowest value (28.16%) of regermination of weeds was recorded in treatment T_2, (Cultivator × 1 + Rotavator × 2) and highest (39.16%) was in treatment T_9, (Desi plough × 4 with a pair of bullocks). Increases in levelof passes of puddling decreased the regermination of weeds and it was lower in Rotavator followed by Cultivator, Desi plough. However, the values were more in higher number of passes of puddling compared to lower passes.

Energy analysis

The cultivation of paddy under transplanting method was partially mechanized as seedbed preparation, puddling, threshing was done by tractor, cultivator and rotavator while sowing, transplanting, fertilizing, harvesting was done by manually. Selection of farm machines was very important for matching field size, in some of the operation using farm machines can be reduce cost and human effort with getting maximum production. The energy input for the puddling operation depends on the actual field capacity and the weight of the puddling equipment used. The energy consumption for puddling operation was found highest in treatment T_8 (Rotavator × 3), 2796.81 MJ/ha while the lowest in treatment T_3 (Cultivator × 1), 475.93 MJ/ha with irrespective of puddling levels. Energy requirement for puddling operation was increased with increase in level of passes of puddling from two to three or four passes.

Table 4: Energy input and energy output in different treatments

Treatments	Energy for Puddle bed (MJ/ha)	Total Input energy (MJ/ha)	Output (MJ/ha)	Energy ratio	Energy Productivity (kg/MJ)	Specific energy (MJ/kg)	Grain Yield (kg/ha)
T_1	1391.85	23167.83	230052	9.93	0.304	2.87	7035
T_2	2292.45	24096.99	234531	9.73	0.298	2.73	7177
T_3	475.93	21730.68	207842.1	9.56	0.286	2.96	6218
T_4	1757.55	23751.12	238562.5	10.04	0.307	2.62	7303
T_5	2606.64	24868.37	251962	10.13	0.310	2.53	7710
T_6	887.48	22325.68	211541.2	9.48	0.283	3.01	6328
T_7	1901.24	23971.82	239665.6	10.00	0.306	2.84	7330
T_8	2796.81	25113.39	249956.9	9.95	0.305	2.57	7648
T_9	1507.24	20527.57	185736.5	9.05	0.270	3.15	5545

The maximum average energy input required was 25113.39 MJ/ha in treatment T_8 (Rotavator × 3) and minimum average input energy was 20527.57 MJ/ha in treatment T_9 (Desi plough × 4 with a pair of bullocks). Overall best output was obtained in treatment T_5 (Cultivator × 2 + Rotavator × 2) with the value 251962 MJ/ha. In treatment T_5 (Cultivator × 2 + Rotavator × 2). The operation wise total input energy 9887. 61 MJ/ha in which highest energy was consumed in irrigation 4125 MJ/ha (41.7%) followed by puddle bed preparation 2606.64 MJ/ha (26.4%), harvesting and threshing 1057.46

MJ/ha (10.7%), nursery preparation 742. 14 MJ/ha (7.5%), transplanting 565.20 MJ/ha (5.7%), weeding 314.00 MJ/ha (3.2%), spraying 198.37 MJ/ha (2.0%), fertilizer application 19.6 MJ/ha (0.2%) in different operations performed under rice crop. Artificial irrigation is required approximately 12 times due to the cultivation being carried out in the summer season. Similarly, the source wise total input energy was accounted 14980.76 MJ/ha in which highest energy was consumed 7013.60 MJ/ha (46.8%) by fertilizer. the second important source was diesel having consumed 3514.40 MJ/ha (23.5%) energy followed by electricity 2091.45 MJ/ha (14.0%). The least energy input was noted under chemical 162 MJ/ha (1.1%).

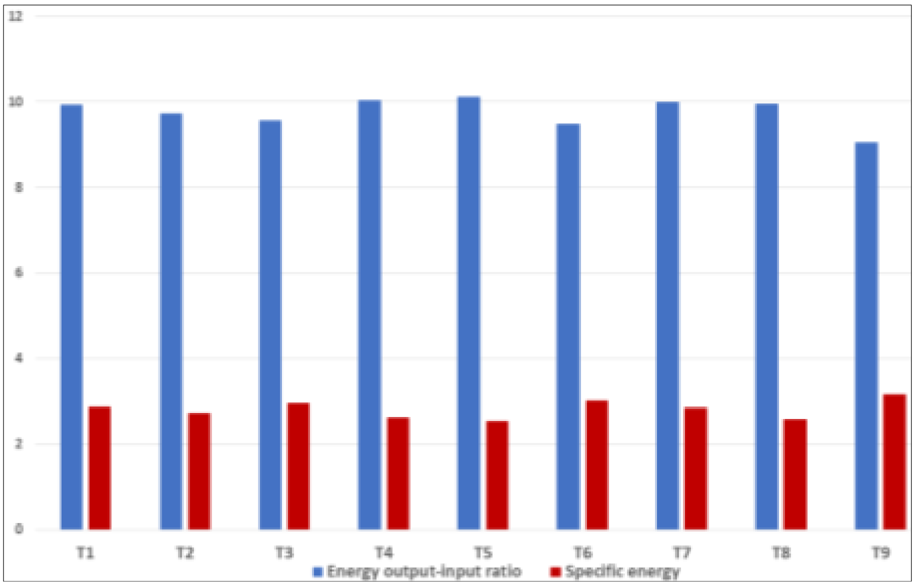


Fig 3: Energy output-input ratio and specific energy

Overall maximum energy output-input ratio, net energy, energy productivity and minimum specific energy obtained in treatment T_5 (Cultivator × 2 + Rotavator × 2) were 10.13, 227093.63 MJ/ha, 0.310 kg/MJ and 2.53 MJ/kg respectively.

4. Conclusions

1. Increase in the level of passes of puddling enhances the puddling index and depth while reducing weed regermination. The highest puddling index (56.90%) and depth of puddling (148 mm) were observed in treatment T_5 (Cultivator × 2 + Rotavator × 2), whereas the lowest weed regermination occurred in treatment T_2 (Cultivator × 1 + Rotavator × 2) at 28.16%.
2. The highest energy input was found for the puddling operation, totalling 2796.81 MJ/ha, and for cultivation, it was 25113.39 MJ/ha in treatment T_8 (Rotavator × 3). The overall best output was obtained in treatment T_5 (Cultivator × 2 + Rotavator × 2) with a total of 251962 MJ/ha. In treatment T_5, the maximum energy output-input ratio, net energy, energy productivity, and minimum specific energy were 10.13, 227093.63 MJ/ha, 0.310 kg/MJ, and 2.53 MJ/kg, respectively.

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