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Study on energy consumption of various rice establishment methods and water management practices in tank irrigated command area

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Abstract
Field experiments were conducted at Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, India, during summer 2019 to find out energy efficient rice establishment methods under irrigation management strategy. Field experiment comprised of four establishment methods in main plot *viz.*, conventional transplanting (M_1), machine transplanting under puddled soil (M_2), machine transplanting under unpuddled soil (M_3) and sowing with seed drill (M_4). The sub plot consisted of 4 irrigation management practices *viz.*, farmers' irrigation practice (continuous submergence of 5 cm throughout the crop period) (I_1), Irrigation after formation of hairline crack (I_2), irrigation when water level reaches 5 cm below soil surface (I_3) and irrigation when water level reaches 10 cm below soil surface (I_4). Medium duration fine grain rice variety TKM 13 was used for the study. Result of the study revealed that among the rice establishment methods higher energy output, net energy production, energy ratio and profitability was observed under machine transplanting under unpuddled soil. Among the irrigation management practices, irrigation after formation of hairline crack (I_2) observed higher energy output and net energy production; whereas, energy ratio, energy productivity, energy intensity and B:C ratio were higher with irrigation when water level reaches 5 cm below soil surface (I_3). This study concluded that machine transplanting under unpuddled soil combined with irrigation when water level reaches 5 cm below soil surface can be recommended as the suitable technology for the farmers of tank irrigated command area to get higher output energy with minimum use of input energy and also to obtain higher profit.

Keywords: Rice establishment methods, irrigation management practices, energy input, energy output, profitability

Introduction
Rice is the most important food crop, eaten by more than half of the world's population. In Asia, the term Food security can be well related to Rice security as 90% of rice is consumed in this region. It is suitable to grow under diverse range of agro ecological zones. In India, rice is grown in an area of 79.77 million hectares with the total production of 105.5 million tonnes (India stat, 2018). In southern parts of India, mostly rice is grown in command areas under tank irrigation system. Major source of water for the tank is rainfall. Due to delayed onset, early withdrawal and decreased quantity of monsoon rains, releasing of water from dams get delayed and the availability of water in tanks for irrigation also get reduced. The rice crop grown in these command areas suffers due to terminal stress and the farmers could not achieve higher yield. Manual transplanting under puddled soil condition is the most common method of rice cultivation. Puddling required 30% of total water required for rice cultivation (Aslam *et al*., 2002) [1], which also destroyed the soil structure (Hobbs and Gupta, 2003) [2], puddling created subsurface hard pan at 15-25cm, it affected the root growth of the rice. Moreover, manual transplanting required 30 man days ha^{-1} (Gill *et al*., 2006) [8]. Labour scarcity in agricultural sector is the emerging problem due to migration of labours from the villages to nearby cities that ultimately delayed the transplanting of rice seedlings and caused irrecoverable yield loss (Aslam *et al*., 2008) [3]. Mechanised transplanting under unpuddled soil condition can be an alternate strategy for manual transplanting under puddled soil

condition, which could save energy and water usage by 31-76 % and 25-26 % respectively than conventional tillage (Islam *et al.*, 2013) [15], ensures timely transplanting and attains optimum plant density that attributes to high productivity and returns. Direct sowing of rice using drum seeder is also considered as an alternate rice establishment method for transplanting, it required only two persons to operate the seeder for seeding a hectare of land (Chandrasekhrarao *et al*., 2013) [5].

In general rice is cultivated like a semi aquatic crop with continuous flooding but it was not necessary, because continuous flooding consumes huge quantity of water. With the available total water, agriculture alone consumed 78.2% of total available water and the availability will shrink to 71.6% in 2025 and 64.6% in 2050 (IWMI, 2008) [16]. It created the need to develop novel technologies that consumes lesser water and produces higher economic returns. Adaption of appropriate water management could save huge quantity of water compared to conventional method of irrigation (Bouman *et al*., 2005) [4]. Irrigation application after disappearance of ponded water is recommended now a days. Safe alternate wetting and drying (AWD) can also be recommended as an ideal water saving technology that demands irrigation when water depth falls to a threshold depth of below the soil surface with the use of field water tube. Several studies concluded that significant reduction in water input can be achieved by safe AWD without penalty in grain yield (Samoy *et al*., 2008) [26].

In production agriculture, energy is the predominant input. Energy is invested in various forms such as mechanical viz., human labour, animal draft and farm machines; chemical fertilizer viz., herbicides and pesticides and electrical, etc. For improved agricultural production, use of right energy in right place is much more important that also improved Effectiveness and efficient use of energy. Optimum use of farm machineries and Implements can increase the productivity and at the same time it minimize the cost of production. So it is highly essential to develop energy efficient methodology for rice cultivation in tank irrigated command area to improve energy use efficiency with improved productivity. With that objective the study was conceptualized and carried out.

Materials and Methods

The field study was carried out in Tamil Nadu Agricultural University, Agricultural College and Research Institute, Madurai, Tamil Nadu, India. The experimental site was located at 9˚54' N latitude and 78˚54' E longitude at an altitude of 147 m above MSL. Soil texture is sandy clay loam, p^H of the soil was 7.2, organic matter of the soil was 0.81%, soil available N-242.6 kg ha^{-1}, available P-16.9 kg ha^{-1} and available K- 432.7 kg ha^{-1}. The experiment was laid out in strip plot design with 16-treatment combination and three replication. The treatments comprised of four different methods of establishment *viz*., conventional transplanting (M_1), machine transplanting under puddled soil (M_2), machine transplanting under unpuddled soil (M_3) and sowing with seed drill (M_4) in main plot and four irrigation management methods in sub plots consisted of water management practices *viz*., farmers' irrigation practice (continuous submergence of 5 cm throughout the crop period) (I_1), Irrigation after formation of hairline crack (each irrigation was given to the depth of 2.5 cm) (I_2), irrigation when water level reaches 5 cm below soil surface (each irrigation was given to the depth of 2.5 cm) (I_3) and irrigation when water level reaches 10 cm below soil surface (each irrigation was given to the depth of 2.5cm) (I_4). Medium duration fine grain rice variety TKM 13 was used for experimentation. The energy and cost were Calculated by operation-wise and source-wise consumption, Energy ratio (output: input) and cost benefit ratio (output: Input). The energy for commercial and non-commercial Sources (human, animal) was also calculated as per the procedure given by Devasenapathy *et al.* (2009) [7]. Cost of each Operation was calculated at present rate in market of different Inputs. The data was collected in field operation and energy use in different operation was calculating by using energy Equivalent as referred by Mittal and Dhawan (1988) [22] (Values were presented in table 1).

Table 1: Equivalents for Input and Output sources of energy

Sl. No.	Particulars	Units	Equivalent energy (MJ)	Remarks
A.	Inputs			
1.	Human labour			
	a) Adult man	Man-hour	1.96	1 Adult woman =0.8 adult man
	b) Woman	Woman-hour	1.57	1 Child = 0.5 adult man
2.	Diesel	Litre	56.31	It includes the cost of lubricant
3.	Petrol	Litre	48.23	It includes the cost of lubricant
4.	Self-propelled machines	kg	64.80	Distribute the weight of the machinery equally over the total life span of the machinery (in hours). Find the use of machinery (hours) for the particular operation in a crop.
5.	Water for irrigation	m^3	1.02	
6.	Chemical fertilizers			
	i) N	kg	60.60	Estimate the quantity of nitrogen, P_2O_5 and K_2O in the chemical fertilizer. Then compute the amount of energy input from chemical fertilizer
	ii) P_2O_5	kg	11.1	
	iii) K_20	kg	6.7	
7.	Chemicals			
	i) Chemicals (granular)	lg	120	
	ii) Chemicals (liquid)	Ml	0.102	
8.	Seed	kg	14.7	
9.	Output			
	Cereal crops	Kg (Dry mass)	14.7	The main output is grains
	Straw	Kg (Dry mass)	12.5	

The following formula were used for calculation of various energy indices

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

$$\text{Energy productivity} = \frac{\text{Output (grain+ byproduct) (kg ha}^{-1}\text{)}}{\text{Energy input (MJ ha}^{-1}\text{)}}$$

$$\text{Specific energy} = \frac{\text{Energy input (MJ ha}^{-1}\text{)}}{\text{Grain yield (kg ha}^{-1}\text{)}}$$

$$\text{Energy intensity} = \frac{\text{Energy output (MJ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

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

Results and Discussion

Table 2: Energy utilization for rice cultivation under various establishment methods

Energy used	Manual transplanting under puddled soil	Machine transplanting under puddled soil	Machine transplanting under unpuddled soil	Sowing with seed drill
Seed energy (MJ)	588	294	294	882
Mechanical energy (MJ)	202	175	175	168
Diesel /petrol energy (MJ)	1464	1520	1295	1351
Chemical energy (MJ)	12053	12053	12053	11982
Water energy used (MJ)	10044	10044	9445	10184
Human energy used (MJ)	250	207	186	188
Total	24601	24293	23448	24755

Table 3: Various energy indices for rice cultivation under various establishment methods and irrigation management practices

	Energy input (MJ ha^{-1})	Gross energy output (MJ ha^{-1})	Net Energy gained (MJ ha^{-1})	Specific energy (MJ kg^{-1})	Energy ratio	Energy productivity (kg MJ^{-1})	Energy intensity (MJ $₹^{-1}$)
Establishment method							
M_1	24601	166905	142305	4.55	6.81	0.51	3.38
M_2	24293	170372	146078	4.37	7.05	0.52	3.66
M_3	23448	176049	152601	4.04	7.56	0.56	4.02
M_4	24755	153039	128283	5.03	6.19	0.46	3.59
Irrigation strategies							
I_1	27379	166176	138797	5.09	6.07	0.45	3.60
I_2	25035	179193	154158	4.27	7.17	0.53	3.87
I_3	22720	174035	151315	4.02	7.67	0.57	3.88
I_4	21964	146962	124997	4.59	6.70	0.50	3.31

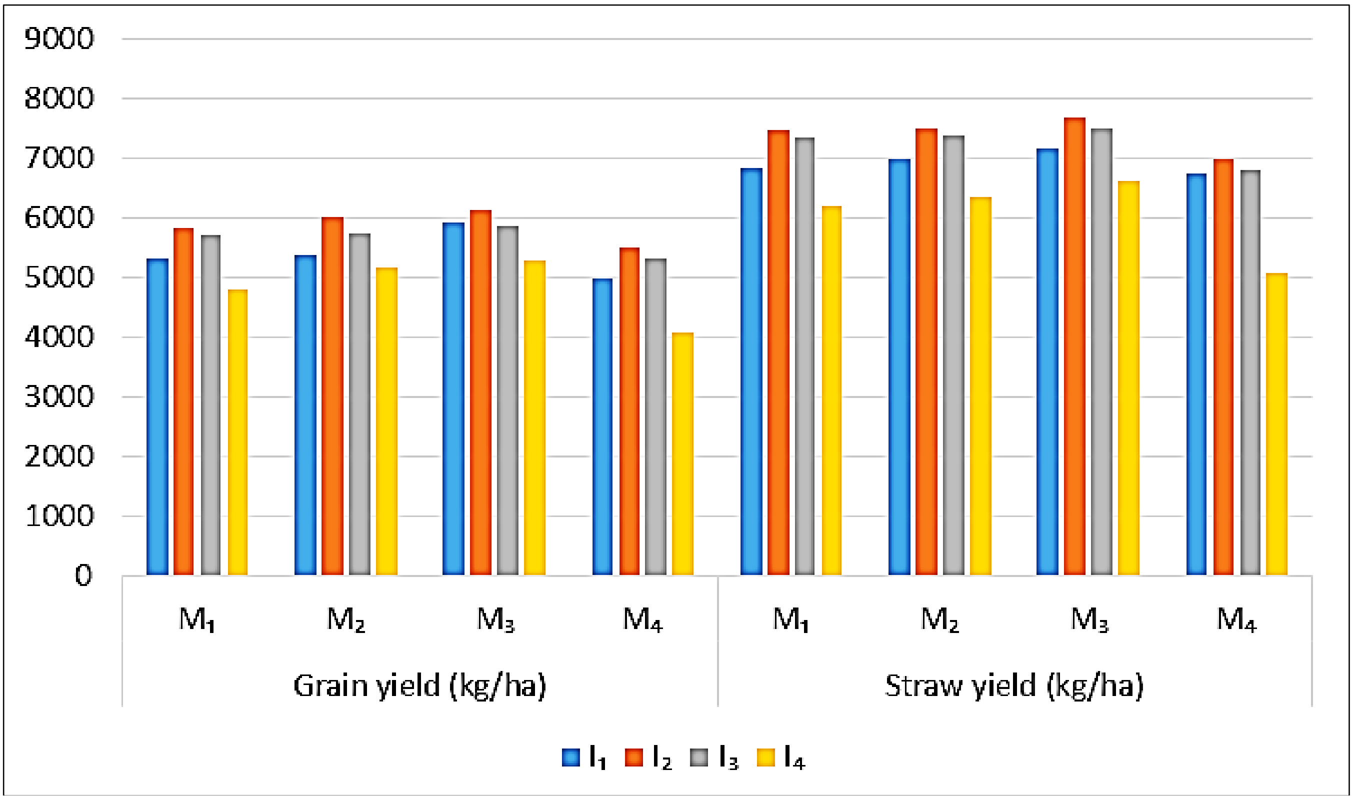

Fig 1: Grain yield and straw yield obtained from various establishment methods and irrigation management practices

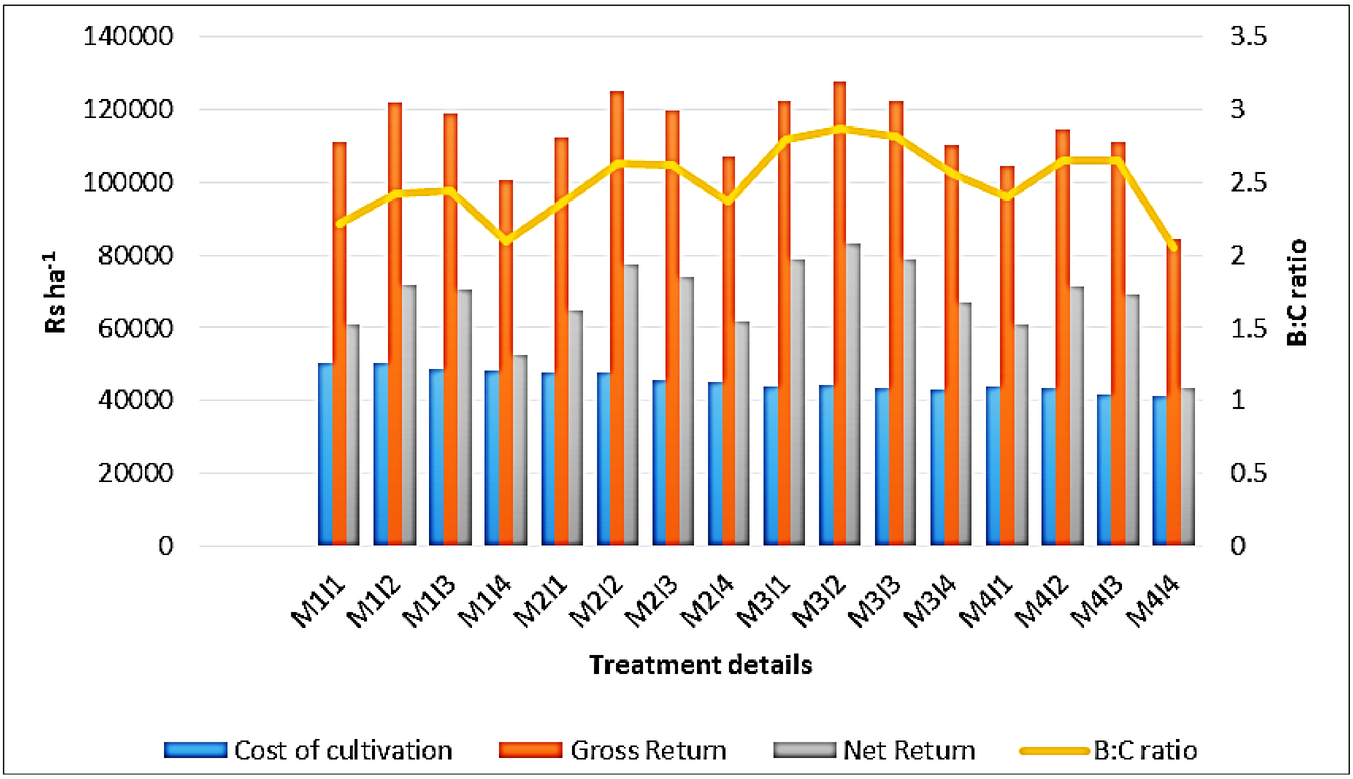

Fig 2: Cost of cultivation, gross return, net return and B: C ratio for various establishment methods combined with irrigation management practices

Energy Budgeting

Energy indices for rice cultivation was positively influenced by the rice establishment methods and irrigation management practices

Input Energy

Among the various establishment methods, sowing with seed drill (M_4) consumed more energy (24755 MJ ha^{-1}) for rice production as compared to other method of establishment (Table 3). Because direct seeding required more seed energy (882 MJ ha^{-1}) over manual (588 MJ ha^{-1}) and machine transplanting method (294 MJ ha^{-1}) (Table 2). Input energy was lesser with machine transplanting under unpuddled soil (M_3), it was mainly due to consumption of lesser mechanical, fuel energy and water energy for field preparation compared to puddled soil (Table 3). These results were in line with Kumar and Ladha, 2011 [18] and Hossen *et al.*, 2018 [13]. Within the irrigation management, farmers' method of continuous flooding irrigation (I_1) recorded higher input energy of 27379 MJ ha^{-1} (Table 3). However, irrigation when water level drops 10cm below soil surface (I_4) recorded lower input energy. It was mainly due to use of lesser quantity of irrigation water compared to farmer's practice of irrigation. This result was in line with Suresh Kumar and Pandiyan, 2018.

Gross output energy and net energy output

Among the establishment methods, machine transplanting under unpuddled soil (M_3) recorded higher gross and net output energy of 176049 and 152601 MJ ha^{-1}, respectively (Table 3). Higher grain and straw yield obtained from this treatment resulted in higher grain yield (Fig. 1.). Sarker *et al.*, 2016 [27] also observed similar result. Whereas, lower output energy was recorded in sowing with seed drill (M_4) due to lower yield (Fig 1). This result was in line with Chhokar *et al.*, 2014 [6]. Among the irrigation management practices, irrigation after formation of hairline crack (I_2) observed increased grain yield (Fig. 1.) which in turn increased the gross and net energy output to 179193 and 154158 MJ ha^{-1}, correspondingly (Table 3). It was followed by irrigation when water level reaches 5 cm below soil surface. Nitrate nitrogen was improved by better aeration in soil that in turn improved growth and yield attributes (Veeraputhiran *et al.*, 2010 and Kannan, 2012) [29, 17]. Irrigation when water level drops 10 cm below soil surface (I_4) observed lower gross and net output energy (Table 3).

Energy Ratio

Energy ratio also followed same trend as like that of gross and net energy output. Improved energy ratio was observed with machine transplanting under unpuddled soil (M_3) (7.56) (Table 3). Islam *et al.*, 2013 [15] also observed the similar result. Between the irrigation management practices, increased energy ratio was observed with irrigation when water level reaches 5 cm below soil surface (I_3) (Table 3). It was followed by irrigation after formation of hairline crack (I_2) (Table 3). Energy ratio was significantly improved due to increased grain and straw yield (Fig 1).

Specific Energy

Specific energy is the amount of energy need to produce per unit of grain yield. Among the different rice establishment methods, lesser specific energy of 4.04 was observed with machine transplanting under unpuddled soil (M_3) (Table 3). However, sowing with seed drill (M_4) consumed more energy to produce per kg of grain (Table 3.). It was mainly due to poor yield (Fig 1.) and usage of higher input energy (seed energy for drum sowing is higher compared to other method of establishment) (Table 2). Between the irrigation management practices, lesser specific energy was recorded with irrigation when water level reaches 5 cm below soil surface (I_3) (Table 3). Because the above said practices recorded higher grain and straw yield (Fig. 1) with the use of lesser total input energy (Table 3).

Energy Productivity

Energy productivity represents the biological yield produced per unit of energy. Among the rice establishment methods, higher energy productivity was observed with machine transplanting under unpuddled soil (M_3) (0.56 MJ kg^{-1}) (Table 3). Nutrient availability in unpuddled soil was higher compare to puddled soil (Mondal *et al.*, 2016) [25], this enhanced the growth and yield of crop (Fig. 1). The same result was confirmed with Islam *et al.*, 2013 [15]. While, sowing with seed drill (M_4) produced lower biological yield by consuming more input energy (Chhokar *et al.*, 2014) [6]. Between the irrigation management practices, irrigation when water level reaches 5 cm below soil surface (I_3) recorded higher energy productivity of 0.57 MJ kg^{-1} due to enhanced plant growth and yield parameters (Fig 1.) compared to other irrigation management practices. Lesser energy productivity was observed with irrigation when water level drops 10 cm below soil surface (I_4) (Table 3). It was mainly due to production of lesser biological yield by consuming more energy compared with other treatments (Fig 1).

Energy Intensity

Energy intensity is the amount of energy produced per unit of cost invested. Among the transplanting methods, machine transplanting under unpuddled soil (M_3) recorded higher energy intensity of 4.02 kg MJ $₹^{-1}$ due to reduced cost of cultivation (Fig 2) and higher grain and straw yield (Fig 1). Lower energy intensity was recorded with conventional manual transplanting (M_1) (Table 3.) with increased cost of cultivation (Fig 2.). Hossen *et al.,* 2018 [13] also observed the similar result. With respect to irrigation management practices, higher energy intensity of 3.90 (Table 1) and B:C ratio (Fig 1) was observed with irrigation when water level drops 5 cm below soil surface (I_3). It was followed by irrigation after formation of hairline crack (I_2). It was mainly due to lesser cost spent for production (Fig 2) for the production of higher output energy.

Conclusion

Machine transplanting under unpuddled soil can be recommended as the best alternate strategy for puddled manual transplanting, because it consumed lesser energy and produced higher output energy and also recorded higher yield and return, which resulted in increased net energy, energy productivity and energy intensity. Among the irrigation management practices, irrigation after formation of hairline crack registered higher output energy, net energy, whereas energy intensity, energy ratio, energy productivity and B: C ratio were higher with irrigation when water level reaches 5 cm below soil surface compared to conventional method of irrigation. It also recorded higher yield and profit. Hence, machine transplanting under unpuddled soil combined with irrigation when water level reaches 5cm below soil surface can be recommended as the best energy saving rice cultivation technique suitable for water scarcity situation prevailing in tank irrigated command areas.

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