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ENERGY CONSUMPTION IN UNPUDDLED TRANSPLANTING OF WET SEASON RICE CULTIVATION IN NORTH WEST REGION OF BANGLADESH

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ABSTRACT

Unpuddled transplanting of rice is gaining attention in Bagnaldesh agriculture. Energy budget is essential for efficient management of the resources in agricultural production. The energy balance under different minimum tillage practices in rice cultivation was assessed during 2009-11 by comparing the parameters: energy input, energy output, energy productivity and energy output:input ratio. Energy input in CT, SPWT, BP and ST were 25.50, 23.15, 20.48 and 20.49 GJ ha^{-1}, respectively in rice cultivation. Maximum energy was consumed for chemical fertilizers. Tillage energy ranked second in conventional tillage and ranked fourth in minimum tillage options. Energy output was insignificant due to insignificant yield difference. Unpuddled transplanting (BP and ST) showed 8-12% increase in energy productivity and 22-24% increase in energy output:input ratio. However, from the energy saving point of view, unpuddled transplanting may be considered better options depending on the resources availability in rice cultivation.

Key Words: Minimum tillage, Direct energy, Indirect energy, Energy productivity, Energy ratio

INTRODUCTION

Effective energy use is one of the conditions for sustainable agricultural production, since it provides financial savings, fossil resources preservation and air pollution reduction (Uhlin, 1998). Productivity of agriculture depends on adequate inputs such as power (farm machines, human labour, animal draft, electrical), improved seeds, fertilizers and irrigation water. Crop yield is directly proportional to the energy input (Srivastava, 1982). In comparison to conventional cultivation with plough, the fuel consumption could be reduced for cultivation by 2 to 3 fold with a strip tillage system (Islam *et al.,* 2012). Fuel and fertilizers (N and P) account for the largest share (>75%) of all energy expenditures in a mixed cropping system (Safa and Tabatabaeefar, 2002). Bockari-Gevao *et al.* (2005) reported that the highest average operational energy consumption was for tillage (1.75 GJ ha^{-1}) which accounted for about 48.6% of the total operational energy consumption (3.6 GJ ha^{-1}), followed by harvesting (1.17 GJ ha^{-1}, 32.6%) and planting (0.56 GJ ha^{-1}, 15.7%) in the lowland

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rice production system in Malaysia. The energy saving of 50% and fuel saving of 30% were achieved by site-specific tillage as compared to uniform-depth tillage in a loamy sand soil type (Alimardani *et al.,* 2007). Due to increasing fuel prices, energy efficiency in crop production became an increasing awareness. Minimum tillage requires less total energy to achieve approximately the same crop production levels as conventional tillage systems (Smith *et al.,* 2002). The energy and agriculture relationship is becoming more and more important with the intensification of the cropping systems. Energy budgets for agricultural production can be used as first step towards identifying crop production processes. The input elements need to be identified in order to prescribe the most efficient methods for controlling them. The benefits of energy analysis are to determine the energy invested in every step of the production process, to provide a basis for conservation and to aid in making sound management and policy decisions for efficient management of scarce resources for improved agricultural production. Rice establishment under unpuddle transplanting system is the new phenomenon and appeared as an emerging technology in rice cultivation. Islam *et al.* (2012) conducted an experiment to establish rice in unpuddled condition and got some exciting results on irrigation water saving and reduction of tillage and cost without grain yield penalty. No such information on the estimate of energy consumption in unpuddled transplating of rice is available. There is a need to estimate the energy consumption in unpuddled transplating of rice cultivation. Therefore, the present research was undertaken to expedite the energy involved in wet season transplanted rice culture under conventional puddling and a range of unpuddled systems.

MATERIALS AND METHODS

Three years trials was conducted at Rajshahi Regional Station, Bangladesh Rice Research Institute during 2009-2011. The experiment was laid out in a randomized block design with three replications (Gomez and Gomez, 1984). The tillage treatment involved conventional tillage (CT), single pass wet tillage (SPWT) as puddle transplating and bed planting (BP) and strip tillage (ST) as unpuddled transplanting. CT consisted of 2 passes primary tillage by two wheel tractors (2WT) and exposed to sun for two days followed by inundating whole plot and puddling by 2WT with 2 passes to complete land preparation. In SPWT, one pass tillage by 2WT after inundating the field. ST and BP were done by Versatile Multi-crop Planter (VMP) in single pass operation before inundating the field. The land was fully inundated one day before transplanting in unpuddled plots. Twenty five-day-old rice seedlings of BR 11 were transplanted in all treatments by hand. Seedlings were transplanted into puddled conditions (CT and SPWT) and unpuddled conditions (BP and ST). The inputs in the form of labour, diesel, seed, chemical fertilizer, plant protection products (insecticides/pesticides/herbicides) used in different stages of crop production and outputs obtained in terms of yield were taken into consideration by appropriate use of energy conversion factors as detailed in Table 1. The energy use was calculated for agronomic operations namely, (i) land preparation, (ii) puddling, (iii) seedling raising & transplanting, (iv) interculture/weeding, (v) irrigation, (vi) crop management and (vii) harvesting and threshing. Energy input was also classified on the basis of source, whether it was direct and indirect. The direct energy input is the energy consumption of physical energy resources for physical work during field operations. Energy input such as human labor and fuel consumption have been considered as direct energy input. Indirect energy is the energy used to produce equipment and other goods and services that are used in the farm.

Table 1. Energy values used in energy calculation

Particulars	Unit	Energy equivalent (MJ unit^{-1})	References
A. Inputs			
1. Human labor	h	0.2014	Bala and Hussain, 1992
2. Machinery	h	62.7	Erdal *et al.*, 2007
3. Diesel fuel	L	56.31	Erdal *et al.*, 2007
4. Chemical fertilizers	kg		
(a) Nitrogen (N)		66.14	Esengun *et al.*, 2007
(b) Phosphate (P_2O_5)		12.44	Esengun *et al.*, 2007
(c) Potassium (K_2O)		11.15	Esengun *et al.*, 2007
(d) Zinc (Zn)		8.40	Argiro *et al.*, 2006
5. a. Chemicals (granular)	kg	120	Canakci *et al.*, 2005
b. Chemical (liquid)	ml	0.102	Gopalan *et al.*, 1978
6. Water for irrigation	m^3	1.02	Acaroglu and Aksoy, 2005
7. Seed	kg	14.57	Bala and Hussain,1992
B. Outputs			
1. Grain	kg	14.57	Bala and Hussain, 1992
2. Straw	kg	12.50	Ozkan *et al.*, 2004

Computation of energy inputs, outputs, productivity and ratio

The energy input, output, output:input ratio as well as the energy productivity in rice cultivation were calculated based on the following formula as described in Chamsing *et al.*, (2006).

Energy input (Ei)

Energy input (Ei), (GJ ha^{-1}) = Ef + Es ……………………………………………………….. (1)

Where,

Ef = energy input in farm operations, GJ ha^{-1}

Es = energy sequestered of machinery, GJ ha^{-1}

Energy input in farm operations (Ef)

Energy input in farm operation (GJ ha^{-1}) = Phy + Chem + Bio ………………………… (2)

Where,

Phy = Physical energy input in farm operation, GJ ha^{-1}

Chem = Chemical energy input in farm operation, GJ ha^{-1}

Bio = Biological energy input in farm operation, GJ ha^{-1}

Energy sequestered in mechanical power sources, (Es)

Energy sequestered in machinery was calculated using following formula.
Energy sequestered (GJ ha^{-1}) = M×h ………………………………………………………… (3)

Where,
M = Energy sequestered in manufacturing of machinery, GJ h^{-1}
h = Machine working hour, h ha^{-1}

Energy output (Eo)

Energy output was based on main product and by-product.
Energy output (GJ ha^{-1}) = (Yield x Eeqm) + (By-product x Eeqb) ……………………… (4)

Where,
Eeqm = Energy equivalent value of main product
Eeqb = Energy equivalent value of by-product

Energy productivity (Ep)

$$\text{Energy productivity (Kg GJ}^{-1}\text{)} = \frac{\text{Crop yield, Kg ha}^{-1}}{\text{Energy inputs to crop production, GJ ha}^{-1}} \quad \text{........ (5)}$$

Energy output-input ratio (Energy use efficiency)

$$\text{Energy output-input ratio} = \frac{\text{Energy output, GJ ha}^{-1}}{\text{Energy inputs to crop production, GJ ha}^{-1}} \quad \text{........ (6)}$$

RESULTS AND DISCUSSION

Source-wise energy distribution

Source wise energy distribution in rice cultivation under different tillage practices is given in Table 2. Direct energy included fuel and human labour. Direct energy consumption accounted for only a small proportion of the total energy consumption ranging from around 9-12% in CT, 6-7% in SPWT, 8-9% in BP and 4-7% in ST. Direct energy was the highest in CT and the lowest in SPWT due to difference in fuel use. Fuel is the main contributor of direct energy with 8-11% in CT, 5-6% in SPWT, 7-8% in BP and 3-6% in ST. Indirect energy consumption included seed, machinery use, fertilizing, plant protection and irrigation. Indirect energy shared 88-91% in CT, 93-94% in SPWT, 91-92% in BP and 93-96% in ST. Indirect energy contributed maximum energy compared to direct energy in rice production. The largest source of indirect energy consumption was from fertilizer 9.93 GJ ha^{-1} (37 to 52 % of the total energy consumption). Seed energy was the highest in ST compared to other tillage operation. Machinery energy was the highest in CT followed by SPWT, BP and ST. Unpuddled transplanting (BP and ST) decreased direct fuel use and reduced indirect machinery use in rice cultivation.

Table 2. Energy consumption (GJ ha^{-1}) based on energy sources under different tillage options for rice cultivation

Source	CT	SPWT	BP	ST
		Rice 2009		
Direct energy				
Fuel	2.20 (8)	2.24 (8)	1.51 (8)	0.54 (3)
Human	0.16 (1)	0.17 (1)	0.25 (1)	0.25 (1)
Subtotal	**2.35 (9)**	**2.41 (9)**	**1.76 (9)**	**0.78 (4)**
Indirect energy				
Seed	0.44 (2)	0.44 (2)	0.44 (2)	0.58 (3)
Machinery	4.39 (16)	3.89 (15)	1.01 (5)	0.60 (3)
Fertilizing	9.93 (37)	9.93 (38)	9.93 (49)	9.93 (52)
Plant protection	3.93 (15)	3.93 (15)	3.93 (19)	3.93 (21)
Irrigation	5.71 (21)	5.71 (22)	3.21 (16)	3.28 (17)
Subtotal	**24.40 (91)**	**23.88 (91)**	**18.51 (91)**	**18.31 (96)**
Total	**26.75 (100)**	**26.30 (100)**	**20.27 (100)**	**19.10 (100)**
		Rice 2010		
Direct energy				
Fuel	2.06 (8)	0.99 (5)	1.33 (7)	1.08 (5)
Human	0.21 (1)	0.24 (1)	0.23 (1)	0.24 (1)
Subtotal	**2.26 (9)**	**1.22 (6)**	**1.56 (8)**	**1.31 (6)**
Indirect energy				
Seed	0.44 (2)	0.44 (2)	0.44 (2)	0.58 (3)
Machinery	4.93 (20)	2.22 (10)	1.04 (5)	0.66 (3)
Fertilizing	9.93 (40)	9.93 (45)	9.93 (49)	9.93 (48)
Plant protection	3.93 (16)	3.93 (18)	3.93 (19)	3.93 (19)
Irrigation	3.54 (14)	4.13 (19)	3.57 (17)	4.38 (21)
Subtotal	**22.76 (91)**	**20.64 (94)**	**18.90 (92)**	**19.48 (94)**
Total	**25.03 (100)**	**21.86 (100)**	**20.46 (100)**	**20.79 (100)**
		Rice 2011		
Direct energy				
Fuel	2.81 (11)	1.27 (6)	1.53 (7)	1.38 (6)
Human	0.17 (1)	0.20 (1)	0.20 (1)	0.20 (1)
Subtotal	**2.98 (12)**	**1.47 (7)**	**1.73 (8)**	**1.58 (7)**
Indirect energy				
Seed	0.44 (2)	0.44 (2)	0.44 (2)	0.58 (3)
Machinery	3.92 (16)	1.96 (9)	1.28 (6)	0.76 (3)
Fertilizing	9.93 (40)	9.93 (47)	9.93 (48)	9.93 (46)
Plant protection	4.38 (18)	4.38 (21)	4.38 (21)	4.38 (21)
Irrigation	3.07 (12)	3.11 (15)	2.97 (14)	4.38 (20)
Subtotal	**21.73 (88)**	**19.82 (93)**	**18.99 (92)**	**20.02 (93)**
Total	**24.71 (100)**	**21.30 (100)**	**20.72 (100)**	**21.60 (100)**

Operation-wise energy distribution

Operational energy was computed for the seedling raising, tillage, transplanting, weeding, fertilizing, spraying, harvesting and winnowing (Table 3). In puddled CT, energy associated with different operations are: fertilizer 37-40%, tillage 25-28%, irrigation 12-21% and plant protection 15-18% of total energy consumption. Fertilizer ranked first and tillage ranked second as input energy in CT.

Table 3. Operation-wise energy input (GJ ha^{-1}) under different tillage options for rice cultivation

Operations	CT	SPWT	BP	ST
		Rice 09		
Seedling raising	0.45 (2)	0.45 (2)	0.45 (2)	0.60 (3)
Land preparation	6.60 (25)	6.16 (23)	2.53 (12)	1.13 (6)
Transplanting and weeding	0.08 (0)	0.08 (0)	0.18 (1)	0.18 (1)
Fertilizer application	9.93 (37)	9.93 (38)	9.93 (49)	9.93 (52)
Plant protection	3.93 (15)	3.93 (15)	3.93 (19)	3.93 (21)
Irrigation	5.71 (21)	5.70 (22)	3.20 (16)	3.28 (17)
Harvesting and winnowing	0.05 (0)	0.05 (0)	0.04 (0)	0.04 (0)
Total	**26.75a (100)**	**26.29a (100)**	**20.27b (100)**	**19.09c (100)**
		Rice 10		
Seedling raising	0.45 (2)	0.45 (2)	0.45 (2)	0.60 (3)
Land preparation	7.01 (28)	3.21 (15)	2.37 (12)	1.74 (8)
Transplanting and weeding	0.12 (0)	0.16 (1)	0.16 (1)	0.16 (1)
Fertilizer application	9.95 (40)	9.95 (46)	9.95 (49)	9.95 (48)
Plant protection	3.93 (16)	3.93 (18)	3.93 (19)	3.93 (19)
Irrigation	3.54 (14)	4.13 (19)	3.57 (17)	4.38 (21)
Harvesting and winnowing	0.03 (0)	0.03 (0)	0.03 (0)	0.03 (0)
Total	**25.03a (100)**	**21.86b (100)**	**20.46c (100)**	**20.79c (100)**
		Rice 11		
Seedling raising	0.45 (2)	0.45 (2)	0.45 (2)	0.60 (3)
Land preparation	6.74 (27)	3.25 (15)	2.81 (14)	2.13 (10)
Transplanting and weeding	0.08 (0)	0.11 (1)	0.12 (1)	0.11 (1)
Fertilizer application	9.94 (40)	9.94 (47)	9.94 (48)	9.94 (46)
Plant protection	4.38 (18)	4.38 (21)	4.38 (21)	4.38 (21)
Irrigation	3.07 (12)	3.11 (15)	2.97 (14)	4.38 (20)
Harvesting and winnowing	0.05 (0)	0.05 (0)	0.05 (0)	0.05 (0)
Total	**24.71a (100)**	**21.30c (100)**	**20.72d (100)**	**21.60b (100)**

Figures in the parenthesis indicate the percentage. In rice 09, $LSD_{0.05}$ = 0.73, CV (%) = 1.57, in rice 10, $LSD_{0.05}$ = 0.49, CV (%) = 1.12 and in rice 11 $LSD_{0.05}$ = 0.13, CV (%) = 0.30

In unpuddled BP, energy associated with different operations was accounted as fertilizer 48-49%, tillage 12-14%, irrigation 15-19% and plant protection 19-21% of total energy consumption. Fertilizer ranked first and tillage ranked fourth as input energy in BP. Similar pattern was observed in puddled SPWT and unpuddled ST. Energy input for fertilizing represented the major part of total input energy (39-52%) which was more than that of percentage energy utilized in fertilizing reported by Chaudhary *et al.* (2006) and Islam *et al.* (2001). Three years average data on rice cultivation showed that energy input was significantly highest in puddled transplanting than unpuddled transplanting (BP and ST). Energy input was the lowest in ST compared to BP due to the lowest land preparation energy whereas, irrigation energy was the highest in ST. SPWT, BP and ST saved 9%, 20%, and 20% energy input, respectively compared to CT. In this study, the lowest percentage of energy input occurred in the minimum tillage and the highest in CT. These findings supported the several investigations that the energy input for fuel consumption can be reduced with minimum tillage management (Franzluebbers and Francis, 1995; Borin *et al.*, 1997) and that the highest energy use occurred with CT (Bailey *et al.*, 2003).

Energy output-input relationship

Energy output-input relationship in rice cultivation is shown in Table 4. Energy gain was varied across the tillage treatment. Differences in energy input and equivalent yield resulted in a large variation of energy balance in wet land rice cultivation. Energy productivity was 8-12% higher in unpuddled transplanting (BP and ST) than puddled transplanting. Energy output-input ratio was found almost identical among SPWT, BP and ST. Energy output-input ratio was the highest in third rice season due to increased yield in all tillage operation. Energy output:input ratio was the highest in unpuddled transplanting than puddled transplanting. Energy output:input ratio was higher by 15%, 22% and 24% in SPWT, BP and ST, respectively compared to CT. Energy output:input ratio tended to increase when soil tillage operations were reduced. This is in agreement with Borin *et al.* (1997). Many researchers reported that minimum tillage maximized the output:input ratio of crop production systems.

Table 4. Energy output-input relationship under different tillage options for rice cultivation

Parameter	**Year**	**Tillage**					
		CT	**SPWT**	**BP**	**ST**	**CV (%)**	**$LSD_{0.05}$**
Energy output (GJ ha^{-1})	2009	123	125	121	122	8.88	NS
	2010	109	119	111	114	1.12	0.49
	2011	187	184	178	180	1.50	NS
	Average	**139.7**	**142.7**	**136.7**	**138.7**		
Energy productivity (kg GJ^{-1})	2009	170	170	220	230	5.80	30
	2010	109	119	111	114	1.12	0.49
	2011	187	184	178	180	1.50	NS
	Average	**155.3**	**157.7**	**169.7**	**174.7**		
Energy ratio	2009	4.6	4.8	6.0	6.5	8.70	0.95
	2010	4.4	5.5	5.5	5.5	6.91	0.72
	2011	7.6	8.6	8.6	8.4	1.77	0.3
	Average	**5.5**	**6.3**	**6.7**	**6.8**		

CONCLUSION

Unpuddled transplanting (BP and ST**)** saved 20% energy input compared to CT in rice cultivation. Energy productivity and energy output:input ratio in unpuddled transplanting was 8-12% and 22-24% higher than conventional puddled. Bed planting and strip tillage were appeared as energy efficient in terms of energy costs and energy produced in rice cultivation.

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