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Energy input-output analysis of rice cultivation in the coastal region of Bangladesh

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Abstract

An analysis of energy input-output in *boro* rice cultivation was undertaken for well recognized salinity classes (S_1-S_5) and farm categories (landless, marginal, small, medium, and large) in south-west coastal Bangladesh. A total of 125 target farmers were surveyed by using structured questionnaire during the *boro* season (January-May 2011). Survey data were converted into energy by using the respective energy co-efficient equivalents. The results revealed that the sequences of total energy input were $S_1 > S_5 > S_2 > S_4 > S_3$ and medium > large > landless > small > marginal among salinity regimes and farm categories, respectively. The seedbed stage consumed the highest energy followed by growing stage, and harvesting and threshing. Inorganic fertilizers accounted for a major share (59.98%) of energy input in rice field, while the lowest share was estimated for manpower (0.75%). Among fertilizers, nitrogen category was the most dominant source (54.94%) of energy input following phosphate (3.82%) and potassium (1.22%). The total output energy was in the sequences of $S_1 > S_4 > S_5 > S_2 > S_3$ and landless > marginal > small > medium > large. Energy from main product (rice grains) was higher than that of by-product (straw). The study also found that total output energy decreases with increases in farm size. In case of energy efficiency (output-input ratio), S_4 was found to be the most energy efficient (2.43) regime followed by S_3, S_1, S_5 and S_2, whereas marginal sized farmers were the most energy efficient (2.12) followed by landless, small, medium and large. This study shows that increased energy input in rice cultivation is not always necessary to get higher output energy in the salinity affected coastal Bangladesh. Therefore, it is necessary to practice environmentally sound management systems for sustainable rice production.

Keywords: energy input-output, *Boro* rice, salinity classes, farm categories, Coastal Bangladesh

1. Introduction

The agriculture sector plays a pivotal role in Bangladesh's economy. It is still the largest employment provider and a significant contributing sector to the gross domestic product (GDP). This sector accommodated around 48.1% of the total labor force of the country in 2010-2011, which was around 51.69% in 2006-2007 (MoF, 2007; BBS, 2011a). The contribution of this sector to GDP growth was 25.03% in 2000-2001, and has been declining almost every year. In 2011-2012, the share of agriculture sector to GDP stood at 19.29% at constant prices (MoF, 2012). The total land area of Bangladesh is 14.39 million hectares (ha) of which around 8.08 million ha were under cultivation in 2000-2001 and it became 7.63 million ha in 2010-2011 (MoA, 2002; MoF, 2012). As of 2010-2011, the cultivable land coverage was: rice 77.07%, pulse 1.7%, wheat 2.5%, oil seeds 2.49%, jute 4.74%, sugarcane 0.78%, potato 3.07%, fruits 0.94%, vegetables 2.45%, and others 4.26% (BBS, 2011b). Cereals (rice, wheat, and maize) are of great importance of Bangladesh's agriculture. In spite of shrinkage of arable land in Bangladesh, the cereal production increased from 26.49 million metric tons (MT) in 2004-2005 to 35.12 million MT in 2011-2012 (MoF, 2012). Over the last eight years, Bangladesh

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has greatly increased its rice production from 25.16 million MT in 2004-2005 to 33.89 million MT in 2011-2012. According to the Bangladesh Economic Survey 2012, the total production of Aus, Aman, and Boro was estimated at 2.33, 12.80, and 18.76 million MT in 2011-2012 as compared to 1.50, 9.82, and 13.84 million MT in 2004-2005, respectively (MoF, 2012). The cultivation of rice usually requires three major resources i.e. land, water and energy. However, salinity has adversely affected both land and water productivity, and slowed down the pace of social and economic development particularly in the coastal regions of Bangladesh.

Agriculture itself is an energy consumer and energy producer in the form of bio-energy (Ramachandra and Nagarathna, 2001). At present the productivity and profitability of agriculture depend on energy consumption (Alam *et al.*, 2005). Srivastava (1982) reported that crop-yield is directly proportional to the energy input. As a result, energy consumption in Bangladesh's agriculture has become more intensive in recent years due to increased cereal production (Alam *et al.*, 2005; MoF, 2012). However, more intensive energy use has brought some important human health and environment issues (Ozkan *et al.*, 2004). The agricultural sector uses a sizable portion of non-commercial energy as solar energy and commercial energy as seeds, fertilizers, pesticides, diesel fuel, electricity (mostly for irrigation), and machinery (Komleh *et al.*, 2011). Efficient use of these energies helps to achieve increased production and productivity, and contributes to the economy, profitability and competitiveness of agricultural sustainability (Singh *et al.*, 2002; Ozkan *et al.*, 2004). Generally, energy requirements in agriculture are divided into two groups being direct and indirect (Ozkan *et al.*, 2004; Alam *et al.*, 2005). Direct energy is essential for performing various tasks related to crop production processes such as land preparation, irrigation, interculture, threshing, harvesting and transportation of agricultural inputs for farm produce (Singh, 2000). It is directly used at farms and on fields (Ozkan *et al.*, 2004). On the other hand, indirect energy consists of the energy used in the manufacture, packaging and transport of fertilizers, pesticides and farm machinery (CAEEDAC, 2000). As the name implies, indirect energy is not directly used on the farm. Energy use depends on the amount of arable land, the number of people engaged in agriculture and the mechanization level (Ozkan *et al.*, 2004; Alam *et al.*, 2005).

The production of rice incurs much higher inputs of commercial energy in Bangladesh including the coastal regions, mainly due to its high water and fertilizer requirements coupled with other practices like transplanting, harvesting and threshing (Khan and Hossain 2007; Halder and Rahman, 2013). If the increase of input energy continues, the total output energy of agriculture will be increased (Alam *et al.*, 2005). However, increase in costs of commercial energy and decline in fuel reserves motivate researchers to work out a more productive agricultural system with better energy use efficiency (Khan and Hossain, 2007). Therefore, an analysis of energy flow in agriculture is utmost important to perform necessary improvements that will lead to a more efficient and environment-friendly production system. Substantial studies have been carried out in abroad on energy flow and transformation (energetics) in crop production.

Ramachandra and Nagarathna (2001) reported a decline paddy yield in spite of greater application of inorganic fertilizers and pesticides in Uttara Kannada district of India. According to this study, application of higher energy inputs in agriculture is not always necessary to get higher production. In the Turkish agricultural sector, total energy input and output increased from 1975 to 2000 (Ozkan *et al.*, 2004). However, there was a decrease in the output-input energy ratio, which indicates the use of inputs in Turkish agricultural production was not accompanied by the same result in the final product. Bockari-Gevao *et al.* (2005) observed the energy output/input ratio of 8.86 that indicates the lowland rice farmers in Malaysia earn at least 8 times of what they put into the production process. Pimentel *et al.* (1973) analyzed the changes in US maize production over a quarter century and showed that yields have increased by 138%, while the energy ratio decreased from 3.72 to 2.8. Rijal *et al.* (1991) examined the total energy requirements and outputs of subsistence agriculture in rural Nepal with special emphasis on animate energy inputs. In this study, the output/input ratio computed for maize, paddy and wheat is relatively higher (2.4-7.5) compared to the highly mechanized agriculture of developed countries (1.5-3.5). They concluded that the energy output/input ratio declines as the level of mechanization increases. Mathew *et al.* (1993) analyzed energy flow patterns in rain fed paddy cultivation under three puddling treatments-bullock drawn plough, power tiller and tractor. Their study reveals that energy consumption per hectare for treatment with bullocks, tractor and tiller was 14.2, 14.2, and 15.0 Gigajoule (GJ), respectively; output/input ratio for tractor, bullock and tiller treatment was respective 7.63, 6.58, and 5.4; and fertilizers and chemicals constitute a major portion of total energy input.

In Bangladesh, however, a very few studies have been carried out on energetics, most of which focused country level situation. Energy input and output to agriculture in the country were increased from 6.4 to 17.32 and 72.22 to 130.05 GJ/ha, respectively, for a period from 1980-1981 to 2000-2001; however, energetic efficiency declined from 11.28% to 8.1%, which indicates that the energy input increased faster than energy output (Alam *et al.*, 2005). Consequently, energy-related problems associated with agricultural production have been occurring. An investigation was undertaken in regional station of Bangladesh Jute Research Institute (BJRI) during the period of 2000-2001 to 2002-2003 to evaluate the energy input, energy output and output-input ratio of some selected jute based cropping pattern (Khan and Hossain, 2007). The highest energy input was noted for jute (oli)-T. aman rice-potato, whereas the lowest for jute (cap.)-T. aman rice-fallow pattern. The highest energy output from main product was recorded in jute-T. aman rice-potato cropping pattern while the lowest from jute-fallow-wheat pattern.

Among the cropping patterns, the highest energy output-input ratio of 14.5 was obtained from jute (cap.)-T. aman rice-fallow followed by 14.0 of jute (cap.)-T. aman rice-lentil and the lowest of 8.5 in jute (oli.)-T. aman rice-potato cropping pattern. They also stated that *rabi/boro* crops had lower energy output compared to other *kharif* crops.

Considering the facts, an analysis of energy flow and transformation in *boro* rice (BRRIdhan-29) cultivation was carried out for well recognized salinity regimes as well as farm categories in south-western part of the coastal Bangladesh. This study would provide planners and policy makers a logical basis to recommend the sustainable energy use for rice production in salinity affected area of the country.

2. Methodology

2.1 Description of the study area

The coastal region covers about 32% area that encompasses a total of 147 upazilas under 19 districts of Bangladesh (Figure 1). According to the Population Census 2001, the total population amounts to 35.08 million, which are 28% of the country's population, residing in 6.85 million households (BBS, 2003). The extent of poverty is relatively high compared with the remaining part of the country: 52% are poor and 24% are extreme poor (PDO-ICZMP, 2003). The region is known as a zone of multiple vulnerabilities as it is prone to several natural disasters, such as cyclone, storm surge, flood, erosion, water logging, water and soil salinity, arsenic contamination in groundwater, and various forms of pollution. However, it has distinctive development opportunities that can be instrumental in reducing poverty and can contribute significantly to the development of the country as a whole.

The region can be broadly divided into three distinct geo-morphological parts: the *eastern part* extends from the Big Feni River to Badar Mokam, the *western pert* comprises an extended patch of natural mangrove forest (the Sundarbans), and the *central part* extends between the eastern and western regions. The region has a subtropical monsoon climate characterized by wide seasonal variations in rainfall, moderately warm temperatures, and high humidity. Several soil types occur in the coastal stretches, which are saline and non-calcareous, except for some soils of the Old Ganges and Meghna floodplain areas (PDO-ICZMP, 2004). The coastal saline area lies about 1.5 to 11.8 meters above the mean sea level. According to the Soil Salinity Map of Bangladesh, out of about 1.689 million ha of coastal land, 1.056 million ha has been affected by varying degrees of salinity (SRDI, 2012). About 0.328, 0.274, 0.189, 0.161 and 0.104 million ha of this affected land falls under very slightly saline area (S_1: 2.0-4.0 dS/m), slightly saline area (S_2: 4.1-8.0 dS/m), moderately saline area (S_3: 8.1-12.0 dS/m), strongly saline area (S_4: 12.1-16.0 dS/m), and very strongly saline area (S_5: >16.0 dS/m), respectively. Generally, tidal flooding through a network of tidal creeks and drainage channels connected to the main river system inundates the soil and impregnates it with soluble salts thereby rendering the topsoil and subsoil salinity. The coastal saline soils are distributed unevenly in 64 upazilas of 13 districts, covering portions of eight agro-ecological zones (AEZ) of the country. The larger portion of saline land falls in the central and western parts, whereas the smaller portion lies in the eastern part of the region. In general, the coastal area is quite low in

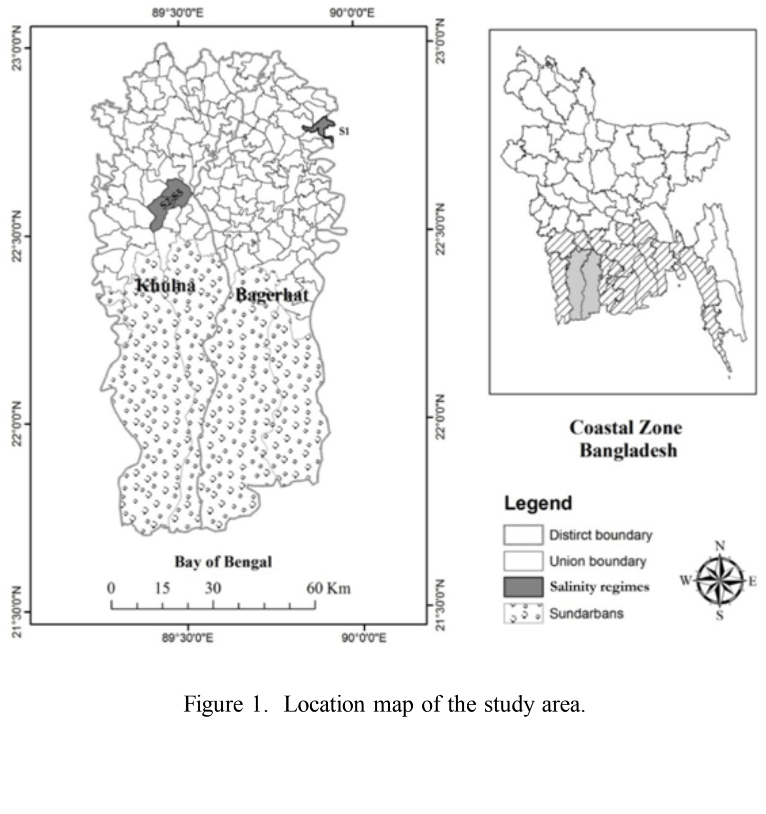

Figure 1. Location map of the study area.

soil fertility; therefore in addition to salinity, nutrients in soil badly affect the plant growth (PDO-ICZMP, 2004; Haque, 2006).

The coastal livelihood is more dominated by agrarian economy compared to rest of the country (BBS, 2002). Over 30% of the net cultivable area of Bangladesh is in the coastal zone, where rice, jute, wheat, cotton, sugarcane, pulses, oilseeds, spices, vegetables and fruits are grown. A total of about 60 different cropping patterns have been identified in coastal area where a considerable change in land use has already been occurred (SRDI, 2012). Farmers usually prefer to cultivate rice in this area where nine modern transplanted *aman* and seven modern *boro* varieties were identified in recent survey (SRDI, 2012). Rice alone is contributing about 16% of the total rice production of the country. In this area, *aman* is the dominant crop, covering about 70% of the total rice cropped area, *aus* covers 16% and *boro* 14% (PDO-ICZMP, 2004).

2.2 Methods of data collection

This study was carried out by collecting both primary and secondary data. Two stage stratified cluster samplings were employed for primary data collection, which are: the salinity regimes and the farmers. Well recognized five salinity regimes of S_1, S_2, S_3, S_4, and S_5 were identified first from south-western part of the coastal region following the Soil Salinity Map of Bangladesh (SRDI, 2012). In this study, S_1 was selected from the Charbaniari union (the smallest administrative unit) under Chitalmari upazila (sub-district) of Bagerhat district, whereas the remaining salinity regimes (S_2-S_5) were selected from Pankhali and Tiladanga unions under Dacope upazila of Khulna district. This selection was based on some homogenous features such as agro-ecological zone, soil types, climate and cropping pattern (SRDI, 2012). The target farmers of landless ($\leq$ 0. 20 hectare (ha)), marginal (0.21-0.60 ha), small (0.61-1.00 ha), medium (1.10-2.00 ha) and large ($\geq$ 2.00 ha) farm sizes were then sampled for interview on agricultural operations and relevant practices from each salinity regime (Iqbal, 2007). A total of 25 farmers, five from each of farm categories (5×5), were randomly selected finally from each of salinity regimes (S_1-S_5) based on the dedication to rice cultivation. Finally, target farmers of 125 were surveyed by using structured questionnaire to collect step-wise and source-wise quantitative energy inputs and outputs in rice cultivation during the *boro* season (January-May).

For the data arrangement and presentation, some steps were followed in this study. Firstly, survey data on farm inputs and outputs were calculated in average for distinct land classes under each of salinity regimes (S_1-S_5). Secondly, calculated data were converted into energy by using the respective energy co-efficient equivalents (Table 1) as suggested by many studies (Bala, 1998; Alam *et al.*, 2005; Khan and Hossain, 2007; Halder and Rahman, 2013). Energy data of all (landless, marginal, small, medium, and large) farm sizes were further calculated in a average for every salinity regime. On the other hand, energy data of all salinity regimes (S_1, S_2, S_3, S_4, and S_5) were also estimated in a average under each farm size. Data were finally presented in tabular form for salinity regimes as well as farm sizes.

Step-wise and source-wise energy inputs were considered in this study. The energy from seed bed, operation and maintenance in the growing field, and harvesting and threshing were calculated as step-wise energy input, whereas energy from human labor, machinery, seed, irrigation, and fertilizer and pesticide applications were calculated as source-wise energy input. In the calculation of energy consumption of machinery, only tractors were considered as the farmers of all regimes usually use these for tillage. Additionally, commercial oils (petrol and diesel) were considered in the estimation of energy consumption of irrigation as electricity-driven pump was not available in the study area. The energy input from conventional sources was ignored as this energy was coming from natural sources. The

Table 1. Energy co-efficient equivalents of inputs and outputs in rice production.

Energy source			Energy co-efficient equivalent
A. Inputs			
	Human labor		0.2014 MJ/hr
	Fertilizer	Nitrogen (N)	60.10 MJ/Kg
		Phosphorous (P)	10.35 MJ/Kg
		Potassium (K)	11.10 MJ/Kg
	Pesticide		120 MJ/Kg
	Diesel		50.32 MJ/L
	Petrol		50.00 MJ/L
B. Outputs			
	Paddy	Seed	14.57 MJ/Kg
		Straw	12.50 MJ/Kg

Data from Bala (1998); Alam *et al.* (2005); Khan and Hossain (2007); Halder and Rahman (2013).

output energy was estimated based on the main product (rice grains) and by-product (straw) of rice cultivation. The net return of energy was calculated by subtracting input energy from output energy. The energetic efficiency (energy output to input ratio) was estimated by dividing the total energy generated from main product and by-product by the total energy used for raising the rice crop. The energy input and output were computed as Mega Joule per hectare (MJ/ha) by the following formula (Khan and Hossain, 2007; Halder and Rahman, 2013):

$$\text{Energy input } (E_i) = E_{hl} + E_{mp} + E_s + E_f + E_p + E_{irr} \quad (1)$$

where E_{hl} is energy from human labor, E_{mp} is the energy from machinery power, E_s is the energy from seed, E_f is the energy from fertilizer, E_p is the energy from pesticide, and E_{irr} is the energy from irrigation. The energy output is given by

$$\text{Energy output } (E_o) = E_{mp} + E_{bp} \quad (2)$$

where E_{mp} is the energy from main product and E_{bp} is the energy from by-product.

3. Results and Discussion

3.1 Analysis of energy input in rice cultivation

The total energy used in rice cultivation varied from 25539.76 MJ/ha in S_3 to 68206.33 MJ/ha in S_1 across different salinity regimes (Tables 2 and 4), whereas 38329.84 MJ/ha in marginal to 39924.93 MJ/ha in medium across different farm sizes (Tables 3 and 5) with an average of 39283.05 MJ/ha. The highest energy inputs were found to be in seedbed stage following operation and maintenance in the growing field, and harvesting and threshing, except S_1 regime and small

Table 2. Energy use (MJ/ha) in rice by step of cultivation and salinity regimes.

Steps of rice cultivation	Salinity regimes					All regimes
	S_1	S_2	S_3	S_4	S_5	
Seed bed	22314.55 (32.72)	24320.3 (66.14)	14250.39 (55.80)	16611.01 (59.00)	27891.44 (73.90)	21077.53 (53.66)
Operation and maintenance in the growing field	45528.55 (66.75)	12056.79 (32.79)	10832.7 (42.42)	11207.34 (39.81)	9503.694 (25.18)	17825.82 (45.38)
Harvesting and threshing	363.234 (0.53)	395.178 (1.07)	456.668 (1.79)	334.894 (1.19)	348.524 (0.92)	379.70 (0.97)
All steps	68206.33 (100.00)	36772.27 (100.00)	25539.76 (100.00)	28153.24 (100.00)	37743.65 (100.00)	39283.05 (100.00)

Note: (i) Step-wise value (MJ/ha) of each salinity regime indicates the average of landless, marginal, small, medium and large farm sizes. (ii) Figures in parentheses indicate the percentage of total energy inputs. Source: Field Survey (2011).

Table 3. Energy use (MJ/ha) in rice by steps of cultivation and farm sizes.

Steps of rice cultivation	Farm sizes					All sizes
	Landless	Marginal	Small	Medium	Large	
Seed bed	20420.19 (51.80)	20518.93 (53.53)	19230.20 (49.12)	20757.66 (51.99)	24460.70 (61.79)	21077.53 (53.66)
Operation and maintenance in the growing field	18570.08 (47.11)	17440.58 (45.50)	19532.80 (49.89)	18825.89 (47.15)	14759.72 (37.28)	17825.82 (45.38)
Harvesting and threshing	430.84 (1.09)	370.32 (0.97)	386.67 (0.99)	341.38 (0.86)	369.29 (0.93)	379.70 (0.97)
All steps	39421.11 (100.00)	38329.84 (100.00)	39149.66 (100.00)	39924.93 (100.00)	39589.71 (100.00)	39283.05 (100.00)

Note: (i) Step-wise value (MJ/ha) of each farm size indicates the average of salinity regimes of S_1, S_2, S_3, S_4 and S_5. (ii) Figures in parentheses indicate the percentage of total energy inputs. Source: Field Survey (2011).

Table 4. Energy use (MJ/ha) in rice cultivation by sources and salinity regimes.

Energy sources	Salinity regimes					All regimes
	S_1	S_2	S_3	S_4	S_5	
Seed	2400.59 (3.52)	18554.93 (50.46)	10455.35 (40.94)	11562.29 (41.07)	18061.55 (47.85)	12206.95 (31.07)
Manpower	419.86 (0.62)	210.18 (0.57)	325.16 (1.27)	233.07 (0.83)	275.05 (0.73)	292.66 (0.75)
Irrigation	4382.24 (6.42)	43.05 (0.12)	37.21 (0.15)	36.64 (0.13)	76.44 (0.20)	915.12 (2.33)
Machinery power	1307.71 (1.92)	2042.01 (5.55)	1413.31 (5.53)	1620.88 (5.76)	1124.63 (2.98)	1501.71 (3.82)
N (fertilizer)	52899.69 (77.56)	14133.40 (38.43)	12119.67 (47.45)	12324.37 (43.78)	16427.10 (43.52)	21580.85 (54.94)
P (fertilizer)	3620.39 (5.31)	1160.36 (3.16)	503.65 (1.97)	1192.11 (4.23)	1030.77 (2.73)	1501.45 (3.82)
K (fertilizer)	1193.03 (1.75)	200.95 (0.55)	143.00 (0.56)	558.43 (1.98)	306.20 (0.81)	480.32 (1.22)
Pesticides	1982.82 (2.91)	427.39 (1.16)	542.41 (2.12)	625.45 (2.22)	441.91 (1.17)	804.00 (2.05)
All sources	68206.33 (100.00)	36772.27 (100.00)	25539.76 (100.00)	28153.24 (100.00)	37743.65 (100.00)	39283.05 (100.00)

Note: (i) Source-wise value (MJ/ha) of each salinity regime indicates the average of landless, marginal, small, medium and large farm sizes. (ii) Figures in parentheses indicate the percentage of total energy inputs. Source: Field Survey (2011).

farm size (Table 2-3). This might be attributed to the highest amount of seed broadcasted in the seed bed as per Ozkan *et al.* (2004). Table 4 partially supports the statement as the seed accounted for a major share of energy input in 40% (S_2 and S_5) of salinity regimes. In all group of farms, seed was also estimated to be the second most important source of energy (Table 5). In general, farmers of the coastal belt broadcasts seed repeatedly in the seed bed as the germination rate of seed is lower and mortality rate of seedlings is higher in saline environment. It was reported that seedling stage of rice is more sensitive to salinity (Zeng and Shannon, 2000; Zeng *et al.,* 2001). Moreover, farmers might have applied more fertilizer per unit area in the seed bed stage of rice cultivation.

On an average, fertilizers of nitrogen, phosphate and potassium accounted for a major share (59.98%) of energy input in rice field followed by seed (31.07%), machinery power (3.82%), irrigation (2.33%), plant protection chemicals (2.05%), and manpower (0.75%) (Tables 4 and 5). Among fertilizers, nitrogen category is observed to be the most dominant source (54.94%) of energy input followed by phosphate (3.82%) and potassium (1.22%). This sequence was also observed in all over the salinity classes as well as in all farm categories. The findings were similar to that of Phipps *et al.* (1976) where fertilizer was major input energy. However, over and indiscriminate usage of fertilizer results in significant reduction in crop yield over a period of time and increases the pollution problems (Ramachandra and Nagarathna, 2001). In 60% salinity regimes (S_1, S_3, and S_4), nitrogen fertilizer shows the highest contribution of energy among estimated eight sources of energy, whereas seed in remaining 40% regimes (S_2 and S_5) (Table 4). The least contribution was calculated for manpower in S_1, S_4 and S_5 while potassium fertilizer in S_2 and S_3. Among the same energy sources, nitrogen fertilizer and manpower were also estimated to be the most and the least dominating sources at all over the farm categories (Table 5).

3.2 Analysis of energy outputs and energy efficiencies

On an average, the total energy output from both main- and by-product was estimated to be 73610.86 MJ/ha that varied from 55229.99 MJ/ha in S_3 to 117762.65 MJ/ha in S_1 across different salinity regimes (Table 6). Across different farm categories, it ranged from 63684.75 MJ/ha in large to 82981.68 MJ/ha in landless farm category (Table 7). It is observed that total energy output produced and energy output from main product decrease with increase in farm size. Between two products, energy from main product shows the

Table 5. Energy use (MJ/ha) in rice cultivation by sources and farm sizes.

Energy sources	Farm sizes					All sizes
	Landless	Marginal	Small	Medium	Large	
Seed	12056.68 (30.58)	12185.81 (31.79)	11570.27 (29.55)	12603.51 (31.57)	12618.46 (31.87)	12206.95 (31.07)
Manpower	385.17 (0.98)	262.14 (0.68)	249.10 (0.64)	249.81 (0.63)	317.08 (0.80)	292.66 (0.75)
Irrigation	544.42 (1.38)	1301.96 (3.40)	933.59 (2.38)	1005.77 (2.52)	789.84 (2.00)	915.12 (2.33)
Machinery power	1548.67 (3.93)	1262.63 (3.29)	1428.93 (3.65)	2026.52 (5.08)	1241.79 (3.14)	1501.71 (3.82)
N (fertilizer)	21929.82 (55.63)	20305.74 (52.98)	21993.62 (56.18)	21508.84 (53.87)	22166.21 (55.99)	21580.85 (54.94)
P (fertilizer)	1903.58 (4.83)	1662.95 (4.34)	1691.50 (4.32)	1130.84 (2.83)	1118.39 (2.82)	1501.45 (3.82)
K (fertilizer)	461.11 (1.17)	431.36 (1.13)	528.42 (1.35)	484.01 (1.21)	496.70 (1.25)	480.32 (1.22)
Pesticides	591.65 (1.50)	917.24 (2.39)	754.23 (1.93)	915.62 (2.29)	841.23 (2.12)	804.00 (2.05)
All sources	39421.11 (100.00)	38329.84 (100.00)	39149.66 (100.00)	39924.93 (100.00)	39589.71 (100.00)	39283.05 (100.00)

Note: (i) Source-wise value (MJ/ha) of each farm size indicates the average of salinity regimes of S_1, S_2, S_3, S_4 and S_5. (ii) Figures in parentheses indicate the percentage of total energy inputs. Source: Field Survey (2011).

Table 6. Average energy output (by sources and salinity regimes) and energy efficiency.

Energy indicators	Sources	Salinity regimes					All regimes
		S_1	S_2	S_3	S_4	S_5	
Energy output	Main product	91456.82 (77.66)	46732.59 (75.27)	39613.40 (71.72)	56215.74 (82.07)	52550.36 (81.50)	57313.78 (77.86)
	By-product	26305.83 (22.34)	15354.38 (24.73)	15616.60 (28.28)	12279.09 (17.93)	11929.50 (18.50)	16297.08 (22.14)
	Total	117762.65 (100.00)	62086.97 (100.00)	55229.99 (100.00)	68494.82 (100.00)	64479.87 (100.00)	73610.86 (100.00)
Total energy input		68206.33	36772.27	25539.76	28153.24	37743.65	39283.05
Net return of energy		49556.32	25314.70	29690.24	40341.58	26736.21	34327.81
Energy efficiency		1.73	1.69	2.16	2.43	1.71	1.94

Note: (i) Energy output (MJ/ha) of each salinity regime indicates the average of landless, marginal, small, medium and large farm sizes. (ii) Figures in parentheses indicate the percentage of total energy outputs. Source: Field Survey (2011).

highest value for all over the salinity classes and for all farm categories (Tables 6 and 7). In case of main product, the average energy output was estimated to be 57313.78 MJ/ha. It varied from 39613.40 MJ/ha in S_3 to 56215.74 MJ/ha in S_4 across different salinity classes, whereas from 46865.89 MJ/ha in large to 65731.64 MJ/ha in landless across different farm categories. The energy output in same function from by-product was found to be 16297.08 MJ/ha, which ranged

Table 7. Average energy output (by sources and farm sizes) and energy efficiency

Energy indicators	Sources	Farm sizes					All sizes
		Landless	Marginal	Small	Medium	Large	
Energy output	Main product	65731.64 (79.21)	64031.34 (78.71)	57104.23 (79.59)	52835.79 (77.37)	46865.89 (73.59)	57313.78 (77.86)
	By-product	17250.04 (20.79)	17315.19 (21.29)	14645.12 (20.41)	15456.19 (22.63)	16818.86 (26.41)	16297.08 (22.14)
	Total	82981.68 (100.00)	81346.53 (100.00)	71749.35 (100.00)	68291.98 (100.00)	63684.75 (100.00)	73610.86 (100.00)
Total energy input		39421.11	38329.84	39149.66	39924.93	39589.71	39283.05
Net return of energy		43560.57	43016.69	32599.69	28367.05	24095.04	34327.81
Energy efficiency		2.11	2.12	1.83	1.71	1.61	1.88

Note: (i) Energy output (MJ/ha) of each farm size indicates the average of salinity regimes of S_1, S_2, S_3, S_4 and S_5. (ii) Figures in parentheses indicate the percentage of total energy outputs.
Source: Field Survey (2011).

from 11929.50 MJ/ha in S_5 to 26305.83 MJ/ha in S_1. For all categories of farm, it varied from 14645.12 MJ/ha in small to 17315.19 MJ/ha in marginal farm size.

The highest value of energy output was estimated in S_1 regime, which might be attributed to the maximum input of energy in rice farm (Table 6) as well as the increased productivity of water and soil in the respective area. Across different farm sizes, energy output of the maximum value was found to be in landless group though the farmers of this group applied the third highest energy input (Table 7). The lowest energy output was observed to be in S_3 regime, which could be due to the least energy applied in this regime. Farmers falling under large farm size harvested the lowest of amount of output energy though they used up the second highest energy for rice cultivation.

On an average, net return (output - input) of energy from the rice field was calculated to be 34327.81 MJ/ha (Table 6 and 7). It varied from 25314.70 MJ/ha in S_2 to 49556.32 MJ/ha in S_1 across different salinity regimes, whereas from 24095.04 MJ/ha in large to 43560.57 MJ/ha in landless across different farm categories. In salt affected coastal Bangladesh, the average energy efficiency (output/input ratio) of rice cultivation was estimated to be 1.94 that varied from 1.69 in S_2 to 2.43 in S_4 across different salinity regimes (Table 6). In different farm categories, the energy ratio ranged from 2.12 in marginal to 1.61 in large farm group with the average of 1.88 (Table 7). It is found that S_4 was the most energy efficient regime in coastal area (Table 6), which might be attributed to the input of lower energy (order of $S_1 > S_5 > S_2 > S_4 > S_3$) and the output of higher energy (order of $S_1 > S_4 > S_5 > S_2 > S_3$). The least energy efficient regime was calculated as S_2, which could be due to the input and output variations of energy as revealed from the aforementioned sequences in parentheses. Table 7 shows that farmers of marginal farm category were the most energy efficient followed by landless, small, medium, and large. This might be attributed to the lowest energy input and the second highest energy output in marginal farm category. The lowest efficiency was estimated for large sized farmers, which likely to be higher input energy and the lowest output energy. It is seen that lower sized farmers were more energy efficient than those of larger sized farmers in rice production in the salinity affected coastal region of Bangladesh.

4. Conclusions

A quantitative energy flow analysis in rice cultivation at south-western part of the coastal region of Bangladesh was studied here based on some sustainable energy indicators which are: energy input per unit area, energy output per unit area, net return of energy (output-input energy) and energy efficiency (output/input energy). On an average, total energy input was estimated to be 39283.05 MJ/ha. The highest input (68206.33 MJ/ha) was recorded in salinity regime of S_1 followed by S_5, S_2, S_4 and S_3. Among different farm categories, the medium sized farmers applied the maximum amount (39924.93 MJ/ha) of energy following large, landless, small and marginal. The highest energy inputs were found to be in seedbed stage at all over the salinity classes (except S_1) as well as farm categories (except small) following operation and maintenance in the growing field, and harvesting and threshing. Among different sources of energy, fertilizers accounted for a major share of energy input in 60% salinity regimes (S_1, S_3, and S_4), whereas seed in remaining 40% regimes (S_2 and S_5). However, fertilizers were the most dominating source of energy at all over the farm categories.

The average total energy output was calculated as 73610.86 MJ/ha. In different salinity regimes, the sequence of energy output was $S_1 > S_4 > S_5 > S_2 > S_3$ whereas landless > marginal > small > medium > large in different farm categories.

It is seen that total energy output produced decreases with increases in farm size. Net return of energy varied from 25314.70 MJ/ha in S_2 to 49556.32 MJ/ha in S_1 across different salinity regimes. It also decreases with increases in farm size. The average energy efficiency was estimated for salinity affected coastal Bangladesh. S_4 was found to be the most energy efficient (2.43) salinity regime followed by S_3, S_1, S_5 and S_2, whereas marginal sized farmers were the most energy efficient (2.12) followed by landless, small, medium and large. The results indicate the recommendation for not using intensive energy in rice production in the salinity affected coastal region of Bangladesh. Therefore, it is necessary to practice environmentally sound management systems for sustainable rice production without affecting other components of the ecosystem.

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