PLANTING AND HARVESTING MECHANIZATION ON PRODUCTIVITY, ENERGY EFFICACY AND PROFITABILITY OF POTATO PRODUCTION

Abstract

Potato occupied the first position among all the vegetables in respect of area andtotal production in Bangladesh. Effective and efficient use of energy are necessary for an improved agricultural production. Therefore, a researchwas undertaken for potato production to assess productivity, quantify energy flow and financial profitability of different production systems. The experimented four systems were manual planting and manual harvesting, machine planting and manual harvesting, manual planting and machine harvesting and machine planting and machine harvesting, respectively. The experiment was conducted at Farm Machinery and Postharvest Process Engineering (FMPE) Division, Bangladesh Agricultural Research Institute (BARI) during 2017-18. Yield of potato including yield contributing characters for different treatments were not significantly varied. Direct energy was the highest in mechanical planting and harvesting system (25%) and the lower manual planting and harvesting system (18%). Indirect energy shared 82% in manual planting and harvesting system, 78% in machine planting and manual harvesting system, 80% in manual planting and mechanical harvesting system, and 75% in machine planting and machine harvesting system, respectively. The largest source of indirect energy consumption was from fertilizer (22-27% for the total energy). The higher specific energy of 1.93 MJ/kg was found in manually planted and mechanized harvesting system. The higher product value was from manual planting and mechanical harvesting system. The highest BCR (2.25) was found from machine planted and machine harvested followed by manually planted and mechanically harvested plot(2.16), machine planted and manually harvested plot(1.93) and manual planting and harvesting (1.91). Thus, mechanically planted and harvested systems can be recommended for potato production since it can reduce 52% labour requirement than manual method and can give higher BCR among the tested production methods.

Introduction

In Bangladesh soil and climatic condition has offered high potential of potato production. Itis the third largest food crop following rice and wheat. Potato occupied 0.464 million hectares of land and itsproduction was 2.410 million tonnes. So, it gained the first position among all the vegetables with respect to area andtotal production (BBS, 2022). In case of efficient farmers, production can be increased by increasing cultivable area or substituting existing technology with more advanced technology. Farm mechanization in Bangladesh grew slowly and accelerated recently due to increased need of timely completion of field operations, better utilization of costly inputs, need to handle large volume of agro-produce and improve quality of work. At present, about 80% land of the country is tilled by 2WTs while the remaining 15% land is covered by tractors (Islam, 2018 and Rahman et al., 2021). Greater energy efficiency in food production systems is required since the projected energy production growth is inadequate and conventional energy sources are limited (Vijayakumar et al., 2023; Hoque, 2017).Potato planter improves quality of work and ensures precision placement and efficient use of costly inputs like seed, fertilizer, etc. (Hoque and Hossain, 2020). Potato digging and harvesting is a cumbersome process. A low cost two-wheel tractor driven potato harvester has been developed in Farm Machinery and Postharvest Process Engineering (FMPE) Division of Bangladesh Agricultural Research Institute (BARI), Gazipur to facilitate small farmers to harvest their potatoes at low cost (Hoque and Hossain, 2020). A potato planter and harvester were developed by BARI for planting and harvesting of potato precisely and effectively. And, besides a potato grader was also developedto grade potato in different desired size for more market value (Hoque et al., 2011). The field capacity of the potato planter, potato harvester and potato grader have been evaluated in the previous year. But use of all the mechanical tools for potato production how can increase productivity, energy efficiency and profitability, yet not evaluated. Energy balance consists of energy inputs which are comprised of consumed energy (direct and indirect) and energy outputs or emitted energy. Effective energy use in agriculture is one of the conditions for sustainable agricultural production which provides financial savings (AghaAlikhani*et al.*, 2013). Many researchers have studied energy and economic analysis to determine the energy efficiency of crop production, such maize (Konieczna*et al.*, 2020), rice (AghaAlikhani et al., 2013), potato (Mohammadi*et al*., 2008), sweet potato (Alam *et al*., 2023). However, no studies have been published on the energy and economic analysis of potato production in Bangladesh. Therefore, this study was undertaken for assessing productivity of potato in different level of mechanization, quantifying input- output energy flow andevaluating energy efficiency and financial profitability of potato production in Bangladesh.

Materials and Method

An experiment was conducted at the research field in FMPE Division, BARI, Gazipur during 2017-18. The soil of the exprimental plot was so fertile with the available textural classes of clay loam in BARI region.The experiment was conducted with standard spacing and the variety was cardinal (BARI Alu-8). The following four treatments of T_1, T_2, T_3 and T_4were tested in farmers' fields with 03 (three) replications of each of them.

T_1=Manual planting+ manual harvesting
T_2=Machine planting+ manual harvesting
T_3=Manual planting + Machine harvesting
T_4=Machine planting + Machine harvesting

Date of planting was 01-12-2018. Plot size was 14 x 6 m^2. Date of harvesting was 10-03-2018. Standard fertilizer dose (116-30-125-120 kg/ha NPKS), weed management practice and irrigation schedule were followed. Two wheel tractor operated potato planter and harvester were used. All the potatowas collected and weighed from all plots. Randomly 1 m^2 area was selected from the main plot for crop biomass, plant height, number of stem, number of tuber per hill, tuber yield per hill, yield. Energy conversion was done with standard energy equivalent as mentioned in Table 1.

Table 1 Energy equivalent (MJ/unit) of energy input and energy output indicators

Parameter	Energy equivalent	Unit	References
Human Labour	1.96	h	Shahin *et al*. (2008)
Machine	62.7	h	Shahin *et al*., (2008), Erdal *et al*. (2007)
Diesel	56.31	l	Islam *et al*., (2012), Erdal *et al*. (2007)
N	64.4	kg	Ozkan *et al*. (2004)
P	11.96	kg	Ozkan *et al*. (2004)
K	6.7	kg	Ozkan *et al*. (2004)

Zn	5	kg	Khosruzzaman*et al*. (2010)
S	1.12	kg	Khosruzzaman*et al*. (2010)
Irrigation water	1.02	m^3	Shahin *et al*. (2008)
Fungicide	145	kg	Khosruzzaman*et al*. (2010)
Potato	3.6	kg	Ozkan *et al*. (2004)

All Energy input and energy output was calculated with the following equations.

Total energy input

Total energy input, GJ/ha = $E_{de} + Ei_e$ (1)

Where,
E_{de} = Direct energy input, GJ/ha
E_{ie} = Indirect energy input, GJ/ha

Direct energy input,GJ/ha = $E_h + E_f$ (2)

Where,
E_h = Human energy input, GJ/ha
E_f = Fuel energy input, GJ/ha

Labour energy input, GJ/ha = $\frac{L \times wdlf \times whl \times L_{eqv}}{A_a}$ (3)

Where,

L = number of labor (person)

wdlf = number of working days for labor (day)

whl = working hour (h/day)

L_{eqv} = Energy equivalent of labour (GJ/h)

A_a = cultivated area (ha)

Mechanical energy input, GJ/ha = $\frac{MF_f \times wh_{mf} \times F_{eqv}}{A_a}$ (4)

Where,

MF_f = Fuel consumption of power source machine (L/h)

wh_{mf} = working hour for farm machine (h)

Feq = Energy equivalent of fuel (GJ/L)

A_a = Cultivated area (ha)

Indirect energy input, GJ/ha = $E_s + E_m + E_{fr} + E_{pp} + E_i$ (5)

Where,

E_s = Seed or biological energy input, GJ/ha

E_m = Machinery energy input, GJ/ha

E_{fr} = Fertilizer energy input, GJ/ha

E_{pp} = Plant protection energy input, GJ/ha

E_i = Irrigation energy input, GJ/ha

Seed was considered as biological energy resources input. Therefore, only seeds were considered to calculate biological energy input.

Total seed input, GJ/ha = Seed x S_{eqv} (6)

Where,

Seed = amount of seed applied, kg/ha and S_{eqv} = energy equivalent of seed, GJ/kg

Energy sequestered in machinery was calculated as following formula.

Total energy sequestered, GJ/ha = M×h (7)

Where,

M = Energy sequestered in manufacturing for machinery, GJ/h

h = Machine working hour, h/ha

Total fertilizer input, GJ/ha =UreaxU$_{eqv}$ + TSPxT$_{eqv}$ + MPxK$_{eqv}$ (8)

Where,

U_{eqv} = Energy equivalent values of urea, GJ/kg

T_{eqv} = Energy equivalent values of triple super phosphate, GJ/kg

K_{eqv} = Energy equivalent values of muriate of potash, GJ/kg

Urea = Urea fertilizer rate applied, kg/ha

TSP = TSP fertilizer rate applied, kg/ha

MP = MP fertilizer rate applied, kg/ha

A_a = cultivated area

Plant protection energy input, GJ/ha$_=$ $E_{pp\text{-}h}$ + $E_{pp\text{-}p}$ (9)

Where,

$E_{pp\text{-}h}$ = Herbicide energy input, GJ/ha

$E_{pp\text{-}p}$ = Pesticide energy input, GJ/ha

Total herbicide input, GJ/ha =Her × H_{eqv} (10)

Where,

Her = Applied rate (kg or lit/ha) of herbicide

H_{eqv} = Energy equivalent (GJ/kg or lit) of herbicide

Total pesticide input, GJ/ha = Pes × P_{eqv} (11)

Where,

Pes = Application rate (kg or lit/ha) of pesticide

P_{eqv} = Energy equivalent (GJ/kg or lit) of pesticide

Irrigation energy input, GJ/ha = $I_w \times I_{eqv}$ (12)

Where,

I_w = Volume of irrigation water, m^3 and

I_{eqv} = Energy equivalent (GJ/m) of irrigation

Energy output

Energy output was considered of main product and by-product.
Total energy output, GJ/ha = (Yield x E_{eqp}) + (By-product x E_{eqb}) (13)

Where,
E_{eqp} = Energy equivalent value of main product and E_{eqb} = Energy equivalent value of by-product

Energy ratio (energy use efficiency), energy productivity, net energy gain and specific energy were calculated using the following relationships (Singh, 2002; Sartori *et al.*, 2005):

$$\text{Output- input energy ratio} = \frac{\text{Output energy (MJ/ha)}}{\text{Input energy (MJ/ha)}} \quad (14)$$

$$\text{Energy productivity} = \frac{\text{Product Output (kg/ha)}}{\text{Input energy (MJ/ha)}} \quad (15)$$

Net energy gain= Output energy (MJ/ha) - Input energy (MJ/ha) (16)

$$\text{Specific energy} = \frac{\text{Input energy (MJ/ha)}}{\text{Product output (Biomass) (kg/ha)}} \quad (17)$$

Operating cost calculation

Operating cost was calculated to determine its economic performance and production cost. Fixed and variable costs were determined. Depreciation, interest on investment, tax, insurance and shelter costs are the components of fixed cost calculation using the following equations (Hoque, 2017).

a. Annual depreciation, D=(P-S)/L (18)

Where, D= Depreciation, Tk/yr

P=Purchase price, Tk

S =Salvage value, Tk

L= Working life of the machine, yr

b. Interest on investment, I=(P+S)/2*I (19)

Where, i= rate of interest

c. Tax, insurance and shelter cost T=3% of P (20)

Total fixed cost per year, FC= (a+b+c)

In variable cost calculation, the cost of fuel, lubricant, and labour were considered. These cost increase with increase of machine use and vary to a large extent in direct proportion to days of use per year.

d. Labour cost per hour, L= Tk/man/h (21)

e. Fuel cost per hour, F= l/h × Tk/l (22)

f. Lubrication oil cost per hour, O= 3% of fuel cost (23)

g. Repair and maintenance cost per year=3.5% of purchase price (24)

Total variable cost= (d+e+f+g) (25)

A simple partial economic analysis was done based on total production. Price of the produce was collected from the local markets to compute total production cost, gross return, gross margin and benefit-cost ratio (BCR) with following formulas

Total product value= Yield (kg/ha) x Price (Tk/kg) (26)

Gross return (Tk/ha)= Total product value – Variable production cost (27)

Net return = Total Product value (Tk/ha) – Total production cost (Tk/ha) (28)

$$\text{Benefit –cost ratio} = \frac{TPV}{TPC} \quad (29)$$

Where

TPV= Total Production value (Tk/ha)

TPC= Total production cost (Tk/ha)

Results and Discussion

Yield and yield contributing characters of potato at Gazipur for different treatments were documented in Table 2. Yield of potato for different potato planting and harvesting methods were not significantly varied since plant height, number of stem per plant, number of tuber per hill, tuber yield per hill were also non-significant. Among the treatments, there was no change in depth and soil cover during planting. Use of potato harvester can open most of the tuber in single pass during harvesting. Potato harvester can reduce number of labour requirement and drudgery than manual harvesting methods but there was no yield change with respect to changeof harvesting methods (Hoque and Hossain, 2020 and Bulgakov, 2021).

Table 2. Yield and yield contributing characters of potato at Gazipur for different treatments

Treatments	Plant height, cm	No. of stem/plant	No of tuber /hill	Tuber yield/hill	Yield (t/ha)
T_1	58.37	5.38	11.28	0.45	19.97
T_2	59.72	5.60	10.44	0.36	19.09
T_3	61.42	5.84	11.95	0.48	21.18
T_4	64.57	6.07	11.89	0.48	21.01
HSD	ns	ns	ns	ns	ns
CV(%)	9.56	12.94	23.73	20.02	14.01

Direct energy was found 18%, 22%, 20%, and 25% in the treatment of T_1 T_2 T_3 and T_4, respectively (Table 3). Direct energy was the highest in mechanical planting and harvesting system (25%) and was lower inmanual planting and harvesting system (18%). Indirect energy shared 82% in manual planting and harvesting system (T_1), 78% in machine planted and manually harvested system(T_2), 80% in manually planted and mechanically harvested system (T_3), and75% in machine planted and machine harvested system (T_4). The largest source of indirect energy consumption was fertilizer which was 22-27% of the total energy consumption (Ghahderijani*et al*., 2024). Machinery energy was the highest in T_4 (17%). Irrigation energy consumption in potato cultivation was 19-23% of the total energy consumption.

Table 3 Source wise energy consumption (GJ/ha) under different tillage options in maize cultivation

Source		**T_1**	**T_2**	**T_3**	**T_4**
Direct Energy:	Human	1.24 (4)	0.88 (2)	0.93 (3)	0.60 (2)
	Fuel	4.44 (14)	7.31 (20)	6.15 (18)	9.16 (23)
	Subtotal	5.68 (18)	8.19 (22)	7.07 (20)	9.77 (25)
Indirect Energy:	Seed	5.40 (17)	5.40(15)	5.40 (16)	5.40 (14)
	Machinery	3.46 (11)	5.54 (15)	4.66 (13)	6.94 (17)
	Fertilizer	8.84 (27)	8.84 (24)	8.84 (25)	8.84 (22)
	Plant protection	1.45 (5)	1.45 (4)	1.45 (4)	1.45 (4)
	Irrigation	7.35 (23)	7.41 (20)	7.37 (21)	7.39 (19)
	Subtotal	26.50 (82)	28.64 (78)	27.72 (80)	30.02 (75)
	Grand Total	32.18 (100)	36.83 (100)	34.79 (100)	39.78 (100)

Figure in the parenthesisindicate the % of the total energy

Energy output-input relationship in potato cultivation is shown in Table 4. The highest output-input energy ration and energy productivity was found in T_1 followed by T_3, T_4 and T_1 which is also aligned with findings of Hamedani et al., (2011) and Mohammadi*et al*., (2008). But the higher specific energy was found in mechanized cultivation system (T_2) (1.93 MJ/kg) flowed by T_4 (1.91 MJ/kg), T_3 (1.71 MJ/kg) and T_1 (1.63 MJ/kg).

Table 4 Energy output-input relationship in potato cultivation

Treatments	Input energy GJ/ha	Output energy GJ/ha	Output-input energy ratio	Net energy gain, GJ/ha	Energy productivity, kg/MJ	Specific energy, MJ/kg
T_1	32.18	71.89	2.23	39.71	0.62	1.63
T_2	36.83	68.73	1.86	31.90	0.52	1.93
T_3	34.79	76.26	2.19	41.46	0.61	1.71
T_4	39.78	75.65	1.90	35.86	0.53	1.91

Benefit-cost ratio of potato cultivation was affected by different cultivation method wasshown in Table 5. The input cost was the higher under manual system (T_1) (104281 Tk/ha). The higher product value was from T_3 for manual planting and mechanically harvested system. The highest BCR (2.25) was found from T_4followed by T_3 (2.16), T_2 (1.93) and T_1 (1.91), respectively.

Table 5 Cost and benefit of potato cultivation as affected by different cultivation method

Treatments	Input cost, Tk/ha	Product value, Tk/ha	Net return, Tk/ha	BCR
T_1	104281	199682.5	95401.58	1.91
T_2	99023.76	190912.7	91888.93	1.93
T_3	98221.31	211825.4	113604.1	2.16
T_4	93396.43	210138.9	116742.5	2.25

Conclusion

Yield and yield contributing characters for different treatments were not significantly varied. Direct energy was the highest in mechanical planting and harvesting system. The largest source of indirect energy consumption was fertilizer. The higher specific energy was found in manually planted and mechanized harvesting system (T_2). The higher product value was found in the system of T_3 for manual planting and mechanical harvesting . The highest BCR was found from T_4 followed by T_3, T_2 and T_1. Mechanically planted and harvested systems could reduce 52% labour requirement and gave higher BCR among the tested production systems.

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