Energetics and Cost Economics of Compost-Turner-Cum-Mixer for Compost Production From Paddy Straw

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Abstract

The effect of the machine and pile parameters on the amount of the energy requirement was studied along with other machine parameters. An experimental set-up was made utilizing compost-turner-cum-mixer having arrangements to vary machine parameters. The energy consumption was determined at three levels of rotor speed (220, 300 and 350 rpm) for different tractor forward speed (1.26, 2.26 and 4.17 km/h) having different blade shapes (straight, L-shaped and knife edge) with varying pile height (0.8, 1.0 and 1.2 m). The results indicated that optimum conditions were found with straight shaped blades at a rotor speed of 300 rpm operating with the tractor forward speed of 2.26 km/h for a pile height maintained at 1.0 m. The energy consumption is the governing factor for the adoption of the technology as it decides the overall cost of production of the compost. The energy consumption for turning of the material per tonne decreased with the number of days passing due to reduction in particle density and moisture content. At optimum conditions, the amount of energy required to handle per tonne of the material was found to be 4.84 kWh. The reduction in the particle size and moisture content from 19.4% to 6.66% causes the reduction in the compost density by 41.84 per cent. All the nutrient contents and various parameters studied were in accordance with the standards set by BIS. Unit tonne production of compost requires about Rs. 281.86 with windrow composting while it took about Rs. 3000.00 with pit method of composting. The windrow method led saving of composing time by 75 days, saving in cost by Rs. 2718 per tonne and thus ensured cost reduction by 90.4 percent. The energetics and cost economics were favourable for commercialization of the technology for mass production of compost. It has a promising potential of entrepreneurship.

Key words: Energy requirement, C: N ratio, compost, cost analysis

1.0 Introduction

The present position of soil health in different parts of India is poor and could be ameliorated with application of organic manures which, in turn, could be prepared making use of different types of biomass including agro biomass. In fact, recycling of biomass to improve soil health has become a necessity in the light of excessive dependence on chemical fertilizers. In India also the biomass has been traditional source of rural energy and word over it is ranked number four as a source of energy. The estimated share of biomass in total energy in India accounts for more than a third of the total energy [5].With the advancement of energy conversion techniques like briquetting and pyrolysis biomass will occupy prominent place as energy source in time to come. The sizeable portion of biomass comes from crop residues for example India produces 889.71 m tonnes crop residue annually [3] and the crops like wheat, maize, rice and sugarcane contribute 330 m tonnes of organic waste. The recycling of these organic wastes is not only an effective means to provide a good source of manure but also ecological necessity to protect the environment. This will encourage much needed organic farming. Composting, a traditional way of converting agricultural waste and cow dung into good quality manure, is considered as a key building block of organic farming. It helps in conservation of the environment, human safety [6].Traditional methods of compost preparation are less efficient and which is why internationally mechanized compost preparation is preferred like pile method as manual preparation of the compost on large scale is an uphill task and needs the back support of machines for achieving the desired objective of enhancing the nutrient status of the exhausted soils. Moreover, the decreasing trend of youths in the farming sector, composting, in particular can be bolstered by incorporating machines to reduce the drudgery, discomfort and laborious operations. In fact, mechanization improves effectiveness, precision and timeliness of operation as well as ensuring less wastage, high capacity and economical.

The pile method involves the turning of piles at frequent intervals by employing the compost-turner-cum-mixer. The economics of the information from stand point of energy and cost is important aspect if mechanization needs to be sustained. A study on the effect of operational parameters of compost-turner-cum-mixer on the energy requirement revealed that by increasing the machine forward speed from 200 to 600 m/h at various rotor speeds of 80, 160 and 240 rpm, led to increase fuel consumption by 14.9 to 19.1 and 26%, the power requirement by 14.9, 23.2 and 26.9%, and the energy requirements by 12.40, 21.50 and 28.10%, respectively, when used the self-propelled turning machine [1]. In another study, 16 turning operations were executed, in each turnover cycle, each pile was turned over twice and the complete operation took 30 min. With labour cost 30 Euro h^{-1}, the total cost of the turning operations was 285Euro. The cost of the complete composting process in the first year amounted to 4200 Euro, making the cost of the compost 0.63 Euro. kg^{-1} [4].As a matter of fact, the most critical factors selecting the turner cum mixer system were the cost requirements and the economic returns from the operation. The tractor pulled mixer- cum -turner requires minimum cost of about (76.7 L. E/ton) followed by the self-propelled agitating (80.2 L.E./ton). The economic returns were estimated at about 18.6 %, 25% and 162 % for the self-propelled agitating front loader and the tractor pulled agitating respectively [2].The energy analysis and cost economics of the newly developed compost-turner-cum-mixer was carried out at IARI base on the real time energy needs in operations and cost involved during a experimental study of mass scale compost production employing pile method and using microbial culture and mechanical agitation.

2.0 Materials and Methods

In a field experimentation, three different piles with a length of 40 m each consisting of paddy straw and leaf litter in a volume ratio of (25:75) after mixing 3-4 days old cow dung. The mass ratio of cow-dung and biomass was 0.44. To enhance the process of composting, specially prepared culture known as Pusa Compost Inoculant of fungus was added keeping a dose of 1000 ml per tone of the material. An indigenously designed and developed tractor PTO operated Compost-turner-cum-mixer consisting of mainly power source, transmission system, frame, distribution system, rotor and hydraulic system powered by 75 hp tractor. The detail specifications are given in **Table 1**. The machine has to operate in tremendously difficult situation so require higher fuel consumption and requires more repair and maintenance due to excessive wear and tear. The machine operating variables were optimized and based on that a set of operating and machine variables were recommended. The recommended values were straight blade shape, rotor speed of 300 rpm, forward speed of 2.26 km/h at a pile height of 1.0m.

Table 1: Specifications of the compost turner-cum-mixer

S.No.	Components	Dimensions
1	Mixing rotor diameter (mm)	400
2	Length and shaft diameter of rotor (mm)	2670 , 63
3	Length of rotor shaft(mm)	2870
4	Hydraulic system with base plate, hoses (5 nos.) and direction control valve (5 nos.)	1000mm stroke,63 mm cylinder dia.
5	No. of blades over rotor surface	42(nos.)
6	Length and width of blade (mm)	260, 80
7	Dimension of Water tank (mm)	1220 x 1350 x 1250
8	Side tank(mm)	1250 x 730 x 760

The energy requirement(ER) of the rotor of the compost turner-cum-mixer depends on the power consumption, machine capacity and density of the compost material. The ER were determined by

$$ER\left(\frac{Wh}{tonne}\right) = \frac{Power\ consumption\ (W)}{Machine\ capacity\ \left(\frac{m^3}{h}\right) x\ Density\ (\frac{tonne}{m^3})}\ x\ turning\ no.to\ maturity$$

2.1 Determination of cost economics

The bill of material of the compost-turner-cum-mixer was prepared along with estimated cost of fabrication. The total cost of compost-turner-cum-mixer was determined based on fixed and variable cost. The cost of pit method of composting were also calculated. The break even point of compost-turner-cum-mixer was calculated along with payback period.

i) **Fixed cost of tractor and compost-turner-cum-mixer**

I. Depreciation
II. Interest
III. Insurance and Taxes
IV. Shelter

ii) **Variable cost of tractor and compost-turner-cum-mixer**

I. Fuel cost
II. Lubricant
III. Labour charges
IV. Repair and maintenance charges

The total cost of operation was determined as sum of the fixed and variable cost. The saving in the cost by using compost-turner-cum-mixer in comparison to pit method of composting was compared. The breakeven point and payback period were computed for compost-turner-cum-mixer.

$$\text{BEP} = \frac{FC}{(CH-C)}$$

Where,

BEP = Breakeven point, h/year
FC = Annual fixed cost, Rs/year
CH = Custom hiring charges, Rs/h
C = Operating cost, Rs/h
CH = (C + 25 per cent over head) + 25 per cent profit over new cost

Payback period,

$$BEP = \frac{IC}{ANP}$$

Where,

PBP = Payback period, Year
IC = Initial cost of machine, Rs
ANP = Average net annual profit, Rs/year
ANP = (CH – C) x AU

Where,

AU = AA X EC

Where,

AA = Average annual use, h/year
EC Effective capacity of machine, ha/h

2.2 Determination of cost of the fabricated machine

The dimensions were determined and bill of materials was calculated based on dimensions and total cost of fabrication of a single unit of the compost-turner-cum-mixer, **Table 2.**The cost of the machine was estimated as Rs 3.0 lakhs.

Table 2: Determination of cost of compost-turner-cum-mixer

S.No.	Part of Machine	Cost, Rs	
		Specifications	
1.	Raw material	different sections	125000
2	Gear pump		6000/-
3	Hydraulic Cylinder Piston	70 mm ram dia, Stroke 3'' (Complete set with on/off system)	63000/-
4	Bearings	3'' ϕ	6000/-
5	Manufacturing Cost		100000/-
	Total		**300000/-**

2.3 Determination of cost of operation of tractor machine system

I) Cost of operation of prime mover (i.e. tractor)

A. Fixed cost

Initial cost of tractor (75 hp), Rs = 10, 000, 00

Depreciation = 90.0

Interest (Rs/h) = 77.0

Housing, taxes and insurance cost Rs = 30.0/h

Repair and maintenance cost Rs = 100.0/h

Fixed cost of tractor, Rs =297.0

B. Variable cost

Fuel and Lubricants cost per hour, Rs 247

Wages of tractor driver = Rs. 18.75/h

Variable cost of tractor, Rs = 265.7

Total cost of operation of tractor (Rs. / h) = 297 + 265.7 = 564.5

II) For compost-turner-cum-mixer

A. Fixed cost

Cost of compost-turner-cum-mixer with all accessories = Rs 300000

Depreciation/h= Rs. 37.5

Interest on investment/h = 32.0

Taxes, Insurance and shelter charges / h = 8.33

Repair and maintenance cost = 20.83

Fixed cost/h for compost-turner-cum-mixer, Rs = 37.5+32+8.33+20.83 = **98.66**

Annual fixed cost of Compost turner-cum- mixer / h, Rs. = 98.66*720 = 71035.2

B. Variable cost

Repair and maintenance cost/h @5 per cent of initial cost **=** 20.83

Labour cost of one person per hour, Rs = 18.75

Total Operating cost of compost-turner-cum-mixer (Rs/h) =138.24

Total fixed cost of tractor and machine =297 + 98.66 = **395.6**

Total variable cost of tractor and machine = 20.83 +18.75 +265.7 = **305.28**

Total cost of operation, Rs/h = 395.6 + 305.28 = **700**

2.4 Calculation of Break-even point and payback period

The break even period was determined by

$$\text{BEP, hour per annum} = \frac{\text{Annual fixed cost}}{(\text{Custom fee, Rs./h} - \text{operating cost, Rs./h})}$$

Annual fixed cost, Rs. / year (Compost turner-cum-mixer) =284832

Custom fee, (Rs. / h) = (cost of operation per hour + 25 per cent overhead charges) + 25 per cent profit over new cost (700.88 +700.88*0.25)*1.25 = Rs. 1095.12/h

Operating cost with tractor, (Rs/h) = 700.88

BEP, h / year = 284832 / (1095.12 – 700.88) = 722.47

Amount handled, tonne/year = 3000/8 * 722.47 = 270927.97

Annual utility, tonne= 3000/8 x 720 = 270000

BEP achieved = 270927.97/270000 *100 = 100.34%

Therefore, BEP is achieved at about 100.34((270927.97/270000) * 100) per cent i.e. 722 hours of the annual utility of 720 hours of mechanical compost turner-cum-mixer**.**

Pay Back Period

$$\text{Pay back period} = \frac{\text{Initial cost}}{(\text{Custom fee} - \text{total operating cost}) \text{x } 720}$$

$$\text{Pay Back Period, year} = \frac{300000}{(1097 - 700.88) x\ 720} = 1.05 \text{ year} = 1 \text{ year (approx.)}$$

3.0 Results

3.1 Influence of selected variables on energy consumption

The amount of energy required for turning the compost holds significant criteria in the adoption of technology of windrow composting. The energy is provided from the PTO shaft of the tractor to the rotor of the compost-turner-cum-mixer. The energy of the rotor indicated the amount of energy required per tonne of the material handled. The observed data indicated that due to reduction in particle size with the progress in the composting process, the energy requirement in turning and mixing decreased. In general, the energy requirement decreased with the increase in the rotor speed from 220 to 300 rpm and continued tends to increase with the increase in rotor speed to 350 rpm, Fig.5.8. The decrease in the energy requirement from 220 to 300 rpm was mainly attributed due to the availability of enough moisture and reduction in the density of materials with progressing time. However, once the moisture gets evaporated, the microbial activity gets reduced and the number of micro-organisms starts to decrease. This led to the filling of the voids and increase the energy requirement from 300 to 350 rpm.

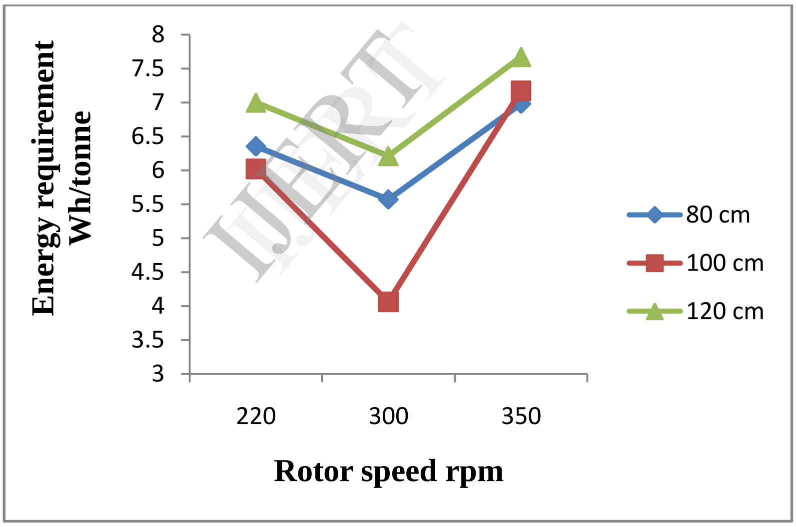

Fig. 1: Variation in energy requirement for straight shaped blade for different rotor speeds (220, 300 and 350 rpm), different pile heights (0.8, 1.0 and 1.2 m) and forward speed of 2.26 km/h.

The statistical analysis indicates that blade shape, rotor speed, forward velocity of tractor and pile height significantly affects the energy consumption at 1 per cent level of significance. The interaction between blade shape, rotor speed and forward velocity significantly influences the energy content at 1 per cent level of significance, **Table 3.**

Table 3: Analysis of variance for energy consumption

Source	Sum of Squares	Df	Mean Square	F-value	P-value
B	40.988	2	20.494	296.916	0.000**
R	36.254	2	18.127	262.624	0.000**
F	65.893	2	32.947	477.326	0.000**
P	10.948	2	5.474	79.305	0.000**
B * R	19.265	4	4.816	69.776	0.000**
B * F	2.640	4	0.660	9.562	0.000**
B * P	0.036	4	0.009	0.132	0.968
R * F	0.096	4	0.024	0.346	0.843
R * P	0.096	4	0.024	0.347	0.842
F * P	0.017	4	0.004	0.060	0.993
R * F * P	0.623	8	0.078	1.128	0.396
B* F* P	00.213	8	0.027	0.387	0.912
B * R * P	0.094	8	0.012	0.171	0.992
B * R * F	5.649	8	0.706	10.230	0.000**
Error	1.104	16	0.069		
Total	3155.985	81			
Corrected Total	183.918	80			

R Squared = .994 (Adjusted R Squared = .970)

Where, B = Blade shape R = Rotor speed

F = Forward speed P = Pile height

In order to determine the level of the parameters that affects the energy requirement of the composing, Duncan method was followed and results are given in **Table 4.**

Table 4: Optimum levels for rotor speed (R), forward speed (F), pile height (P) and shape of blade (B) by Duncan method.

	R	N	Subset 1	Subset 2	Subset 3
Duncan	1	27	5.1589		
	3	27		6.2500	
	2	27			6.7633
	Sig.		1.000	1.000	1.000

	F	N	Subset 1	Subset 2	Subset 3
Duncan	1	27	4.8148		
	3	27		6.4293	
	2	27			6.9281
	Sig.		1.000	1.000	1.000

	P	N	Subset 1	Subset 2	Subset 3
Duncan	1	27	5.6163		
	3	27		6.0396	
	2	27			6.5163
	Sig.		1.000	1.000	1.000

	B	N	Subset 1	Subset 2	Subset 3
Duncan	2	27	5.1670		
	1	27		6.0970	
	3	27			6.9081
	Sig.		1.000	1.000	1.000

The results indicate that the optimum energy requirement occurred when knife edged blades was used with rotor speed of 300 rpm operating at a forward speed of 2.26km/h with pile height of 100 cm. The optimum conditions results in energy requirement of 4.06 kWh/tonne of the material handled. However, with straight shaped blades under the same conditions, the energy requirement was observed as 4.84 kWh/tonne which itself shows the close proximity with the knife shaped blades. There was decrease in energy requirements by increasing forward speed which was attributed to increase in machine capacity at higher forward speed. But at the same time, energy requirements increased slightly by increasing forward speed from 2.26 km/h to 4.17 km/h because influence of speed on energy was dominating.

Thus, considering the overall scenario, the optimum conditions were obtained with straight shaped blades, rotor speed of 300 rpm, forward speed of 2.26 km/h at a pile height of 1.0 m.

3.2 Cost economics of the turner cum mixer

Finally, cost economics of the machine was done in terms of saving in comparison to traditional pit method. The different cost parameters of the machine operation were also determined to find the commercial viability of the machine operation and its potential entrepreneurial.

3.2.1 Comparison of cost economics in traditional pit method with the advanced mechanized pile method

The traditional method of pit composting helped s to prepare good quality compost. However, this method is opted for smaller area and involves the construction of permanent cemented pits. The cost of the permanent structure adds to the overall cost of the compost produced and hence, uneconomical. The initial cost of raw materials utilized for preparation of one tonne of compost included construction of one pit as Rs. 15000, raw materials as Rs. 50, Culture Rs. 30 per bag. The pit composting requires approximately Rs. 3000 per tonne of the compost prepared which includes labour cost, construction, raw materials, cow dung and culture. On the other hand, the compost turner-cum-mixer is used throughout the year for the turning operation. It allows to handle bulk of the material efficiently with less energy requirement per tonne of the material composted. The cost per tonne of material prepared using mechanized pile method was approximately Rs. 281.86, led to a saving of Rs. 2718 (90.4 %) which itself depicts the need of mechanized system in composting, Table 5.

Table 5: Comparison of cost of compost preparation by pile to pit method

Compost	Pit method (10 m x1 m x1 m)	Pile method
Amount of compost prepared	1 tonne	1 tonne
Cost of preparation of one tonne	3000	281.86
Saving in cost, Rs/ tonne	2718	
Saving in time	120days	45 days
Percentage saving	90.4	

3.3 Cost economics of the mixer-cum-turner for compost making

The application of compost not only adds various nutrients but also helps to sustain and improve the crop production. The energetic and cost economics of the machine is also very important for its commercial viability. The cost evaluation of the machine revealed the urgency of utilization of the machine for compost preparation. The advantageous factor of the machine lies in handling large-scale production of compost with low cost per tonne of material. The machine has the capability to handle about 270927.97 tonne of the material per year. The operation hourly cost of compost turner cum mixer with a 75 hp tractor was Rs 700 and Break Even Point 722 hours per year and the annual utility of the machine could be 0.3 lakh tonne of compost. The time during which the entire money invested on the machine can be replayed i.e. Payback period was determined as one year. The cost of production of one tonne of compost by pit method was quite high which could be reduced drastically as the mechanized pile method of composting saved 90.4 % cost of production in comparison to traditional method. Moreover, the saving in the time with compost-turner-cum-mixer was the unique salient point of the mechanized pile system. A saving of 75 days per cycle in compost preparation was obtained ensuring year long preparation of compost on mass scale. Thus, the windrow composting via compost-turner-cum-mixer offers potential for preparation of good quality compost at cheaper rates. The machine in combination with the loader can efficiently reduce the drudgery and cost and led to the preparation of finest quality compost.

Table 6: Operational capability of compost-turner-cum-mixer

Total cost of operation of the machine and tractor, Rs/h	700
Operating cost of compost-turner-cum-mixer (Rs/h)	138.24
Break-even point, h / year	722.47
Amount of material handled, tonne/year	270927.97
Annual utility, tonne	270000
Pay back period	One year

4.0 Discussion

The cost of production of one tonne of compost by pit method was determines as, approximately Rs. 3000 where as the mechanized pile method of composting saved 90.4 % cost of production. The operation hourly cost of compost turner cum mixer with a 75 hp tractor was Rs 700, the payback period 1.0 year and Break Even Point 722 hours per year and the annual utility of the machine could be 0.3 lakh tonne of compost. In fact, the energetics and cost economics of the machine is also very important for its commercial viability. The high capacity of the machine and its robust making is important aspect of the machine. This in fact led to saving of 75 days per cycle in compost preparation using mechanized pile method in comparison to traditional pit method. As a matter of fact, the high capacity and capability of mass production of compost by use of this machine is its unique salient point. The accelerated compost preparation is attained by fats decomposition of biomass in presence of culture which adds to its capability. This is, thus, the potential technology for mass production of good quality compost. With the help of one mechanized loader and high capacity sieving system, the quality compost production can be accomplished which has a great amount of entrepreneurial potential. The popularization of the technology may bring revolution in soil health improvement programmes.

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