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Energy Cost of Riding and Walking Type Power Tillers

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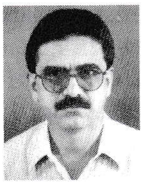

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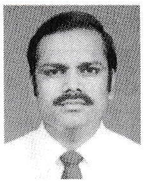

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Abstract

The ergonomic aspects of the power tiller are of great importance as working with thepower tiller involves considerable physiological strain to the operator. The physiological response of the subject while operating two power tillers with one as walking type (7.46 kW) and the other as riding type (8.95 kW) was investigated. The selected operations included rotary tilling in untilled and tilled fields and transport on farm and bitumen roads. The selected levels of forward speed of operation were 1.5, 1.8, 2.1, 2.4 km h^{-1} and 3.5, 4.0, 4.5, 5.0 km h^{-1} for field and transport operations respectively. Three subjects were selected based on the age and weight and screened for normal health through medical investigations. The physiological cost of power tiller operation was computed and the energy cost of work was graded. The oxygen uptake in terms of VO_2 max was compared with acceptable workload and the work pulse was compared with limit of continuous performance. For rototilling in an untilled field the energy cost of work varied from 17.13 to 20.09 kJ min^{-1} for the walking type (7.46 kW) power tiller and 13.95 to 15.43 kJ min^{-1} for riding type (8.95 kW) power tiller. In thetilled field the values varied from 15.70 to 18.23 kJ min^{-1} and 13.28 to 14.59 kJ min^{-1}, respectively. The operations were generally graded as "moderate work". The rototilling operation in an untilled field was strenuous as it demanded 9.1 to 10.20 percent and 1 to 6 percent more energy for walking type (7.46 kW) and riding type power tillers (8.95 kW), respectively than in a tilled field. Power tiller with seating attachment resulted in saving of 23 to 30 percent and 18 to 25 percent human energy requirement in untilled and tilled fields, respectively. In transport mode the energy cost of work varied from 10.17 to 11.12 kJ min^{-1} and 11.32 to 12.82 kJ min^{-1} with 7.46 kW and 8.95 kW power tillers, respectively. The operation was generally graded as "light work" to "moderate work". When compared to the 8.95 kW power tiller, the 7.46 kW power tiller resulted in savings of human energy requirement of 15.33 to 16.23 percent on farm roads and 4.9 to 11.3 percent on bitumen road. For field operation with the walking type power tiller, the oxygen uptake interms of the olxgen consumption rate (VO_2) max varied from 35.30 to 43.93 percent

which was above the acceptable work load whereas the values varied from 29.04 to 33.74 percent for the riding type (8.95 kW) power tiller and was within the acceptable workload. During transport mode, oxygen uptake in terms of VO_2 max varied from 22.24 to 28.03 percent and the values were within the acceptable limit for both power tillers. The work pulse (Δ HR) varied from 21.08 to 37.79 percent for field operations and 11.42 to 19.88 for transporting operations and were within the limit of continuous performance.

Introduction

The ergonomic aspects of power tillers are of great importance as working with the power tiller involves considerable physical strain to the operator. Controlling the power tiller while turning causes considerable fatigue to the operator. An operator has to walk behind the machine for adistance of about 15 to 20 km, merely to rototill a hectare of land once. The problem is aggravated when walking behind the machine in puddled soil during the rotopuddling operation in rice fields (Mehta et al., 1997). The working performance of a power tiller depends not only on the machine but also on the operator. If ergonomic aspects are not given due consideration, the performance of the man-machine system will be poor and effective working time will be reduced. On the other hand, due to heavy demand on the worker's biological systems, the power tiller operation results in clinical and anatomical disorders and in the long run, will affect the workers health (Tiwari and Gite, 1998). In the present study the energy cost of operating walking and riding type power tiller was compared and reported.

Review of Literature

The heart rate for power tiller tillage operation was observed in the range of 105 beats min^{-1} to 114 beats min^{-1}. The corresponding human energy requirement was in the range of 13.22 to 20.52 kJ min^{-1} (Pawar, 1978). Kathirvel et al. (1991) observed that energy expenditure of power tiller operation varied from 13.48 to 25.83 kJ min^{-1} during rototilling operation under different operating conditions. The heart rate was used as the index of physiological cost. Mc Ardle et al. (1994) reported that energy expenditure during walking was influenced by the walking speed and terrain conditions. Tiwari and Gite (1998) measured heart rate and oxygen consumption of the power tiller operators during rototilling operations under actual field condition. The mean values for human energy expenditure during rototilling operations were 10.02, 12.11 and 13.15 kJ min^{-1} at the forward speeds of 1.09, 1.69 and 2.26 km h^{-1} respectively. Mamansari and Salokhe (1999) assessed the physiological cost of the most commonly used power tiller in Thailand in terms of heart rate of the operator and reported that the surface condition of the agricultural field was another factor contributing to operator workload. Tiwari and Gite (2000) evaluated the physiological cost of a 10.5 kW rotary type power tiller with and without seating attachment. Mean heart rate and oxygen consumption rates varied from 85.1 to 90.2 beats min^{-1} and 6.68 to 8.98 kJ min^{-1}, respectively, with the increase in forward speed from 1.04 to 4.14 km h^{-1} with seating attachment. Without seating attachment the heart rate and oxygen consumption rate varied from 90.3 to 134 beats min^{-1} and 8.77 to 16.07 kJ min^{-1}, respectively.

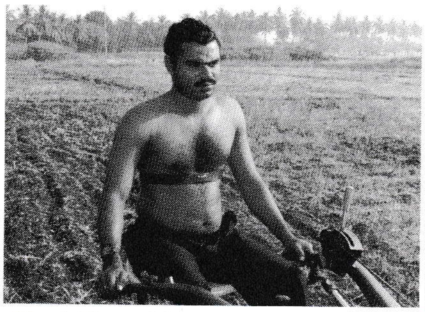


Fig. 1 View of the measurement of heart rate during the operation of power tiller B in untilled field

Fig. 2 View of the measurement of heart rate during the operation of power tiller A with trailer attachment on farm road

Methods and Materials

Among different makes of power tillers popular among the farmers of the study region, two power tillers with one as walking type (7.46 kW) and the other as riding type (8.95 kW) were selected. The selected operations included rotary tilling in untilled and tilled fields and transport on farm and bitumen roads. The selected levels of forward speed of operation were 1.5, 1.8, 2.1, 2.4 km h^{-1} and 3.5, 4.0, 4.5, 5.0 km h^{-1} for field and transport operations, respectively. Three subjects were selected based on the age and weight and screened for normal health through medical investigations. The selected subjects were well acquainted with the controls of power tiller and had experience of operating power tillers under different terrain conditions. All the three subjects were calibrated in the laboratory condition by assessment of oxygen uptake in response to heart rate and their maximum aerobic capacity was computed. The physiological response was assessed through the measurement of heart rate for field and transporting operations.

The power tiller was put in proper test condition before conducting the trails. It was in full working order with full fuel tank and radiator, without optional front weights and any specialized components. Tires used for the tests were of standard size and depth of treads was not less than 70 percent of depth of a new tread. The mean dry bulb temperature, wet bulb temperature and relative humidity varied between 25 to 32 °C, 18 to 25 °C and 25 to 76 percent respectively during the period of evaluation.

The experiment was conducted at different time intervals of the day between 8:30 AM and 5:00 PM as the effect of environmental condition causes changes in heart rate values of the subjects. To minimize the effects of variation in environmental and soil factors, the treatments were given in randomized order. All the three subjects were equally trained in the operation of power tiller with rotavator. The subjects were given information about the experimental requirements so as to enlist their full cooperation. They were asked to report at the work site at 8:00 AM in post-absorptive stage and have a rest for 30 minutes before starting the trial. A rest period of 90 minutes was given between the three trials on the same day, with the same subject.

After 30 minutes of resting, the subject was asked to operate the power tiller (already started by another person and engine throttle position set at required engine speed and gearshift lever in the required position corresponding to the selected forward speed) for a duration of 15 minutes. The duration of measurement was fixed as 15 minutes in accordance with the physiological studies conducted by Tiwari and Gite, 1998 and Vidhu, 2001. The speedometer was monitored to be achieve a constant speed through out the period of investigation.

Table 1 Energy cost of power tiller A and B during rototilling

Forward speed, km h^{-1}	Power tiller	Operation	Energy cost, kJ min^{-1}	Grading of work
1.5	Walking type (A)	Rototilling in intilled field	17.13	Monderate work
		Rototilling in tilled field	15.70	
	Riding type (B)	Rototilling in intilled field	13.95	
		Rototilling in tilled field	13.28	
1.8	Walking type (A)	Rototilling in intilled field	17.98	Monderate work
		Rototilling in tilled field	16.06	
	Riding type (B)	Rototilling in intilled field	14.49	
		Rototilling in tilled field	13.72	
2.1	Walking type (A)	Rototilling in intilled field	19.01	Monderate work
		Rototilling in tilled field	16.91	
	Riding type (B)	Rototilling in intilled field	14.99	
		Rototilling in tilled field	14.01	
2.4	Walking type (A)	Rototilling in intilled field	20.09	Monderate work
		Rototilling in tilled field	18.23	
	Riding type (B)	Rototilling in intilled field	15.43	
		Rototilling in tilled field	14.59	

Table 2 Energy cost of power tiller A and B during transport

Forward speed, km h^{-1}	Power tiller	Operation	Energy cost, kJ min^{-1}	Grading of work
3.5	Walking type (A)	Transport in farm road	10.50	Light work
		Transport in bitumen road	10.17	
	Riding type (B)	Transport in farm road	12.11	
		Transport in bitumen road	11.32	
4.0	Walking type (A)	Transport in farm road	10.89	Light work
		Transport in bitumen road	10.69	
	Riding type (B)	Transport in farm road	12.36	
		Transport in bitumen road	11.15	
4.5	Walking type (A)	Transport in farm road	10.83	Light work
		Transport in bitumen road	10.78	
	Riding type (B)	Transport in farm road	12.69	
		Transport in bitumen road	11.42	
5.0	Walking type (A)	Transport in farm road	11.05	Light work
		Transport in bitumen road	11.12	
	Riding type (B)	Transport in farm road	12.82	
		Transport in bitumen road	11.67	

a. Rototilling

The experiment was carried out in the field using a rotavator in both untilled and tilled conditions. The soil was sandy clay with 48.47 percent clay, 40.47 percent sand and 9.1 percent silt. The soil moisture and bulk density were 11 percent (d.w.) and 1.31 g cm^{-3} for untilled and 7 percent (d.w.) and 1.2 g cm^{-3} for tilled conditions. The surface condition of untilled field was dry and undulating with a weed intensity of 370 g m^{-2}. The surface condition of tilled field was dry with small undulations and without weeds. The recommended tire pressure (1.5 kg cm^{-2}) was maintained for the wheels. Depth of operation was maintained at about 15 cm throughout the period of investigation. The trials were conducted at the selected four levels of forward speed with both the power tillers in untilled and tilled field. The heart rate was measured and recorded using a computerized heart rate monitor for the entire work period. The same procedure was repeated three times for all the selected subjects. The view of the measurement of heart rate during the operation of power tiller B in untilled field is shown in **Fig. 1**.

b. Transporting

The tests were carried out on farm roads and bitumen roads on transport mode of power tiller attached with an empty trailer for both power tiller A and B at four levels of forward speed. The recommended tire pressure (2.5 kg cm^{-2}) was maintained for the wheels. The heart rate of the subject was measured and recorded using computerized heart rate monitor for the entire work period. Measurements were taken for 15 minutes duration and repeated three times for each subject. A view of the measurement of heart rate during the operation of power tiller A with trailer attachment on a farm road is shown in **Fig. 2**.

The recorded heart rate values from the computerized heart rate monitor were downloaded to the computer through the interface provided for all the operations. From the down loaded data, the values of heart rate at the resting level and at the 6^{th} to 15^{th} minute of operation were taken for calculating the physiological responses of the subjects. From the mean value of heart rate (HR) observed during the trials, the corresponding values of oxygen consumption rate (VO_2) of the subjects for the selected operations were predicted from the calibration chart of the subjects. The energy cost of operation was computed by multiplying the oxygen consumed by the subject with the calorific value of oxygen (20.88 kJ lit^{-1}) (Nag et al., 1980) for all the subjects. To ascertain whether the operation of the power tillers was within the acceptable workload (AWL), it was necessary to compute the VO_2 max for each subject.

Results and Discussion

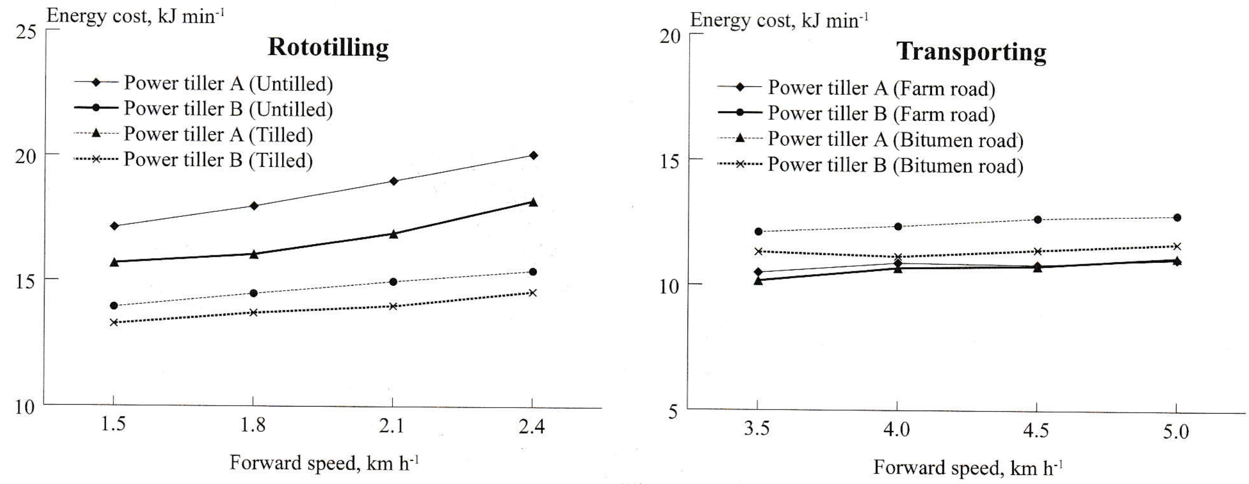
i. Energy Cost of Operation

The physiological response of the subjects during rototilling with a walking type power tiller (A) and riding type power tiller (B) in untilled and tilled fields and grading of the work are furnished in **Table 1**.

Based on the mean energy expenditure, the operation was graded as "moderate work" for all the selected levels of forward speed (Rodahl, 1989). Comparison between untilled and tilled field operation showed a marked difference in the energy expenditure between the terrain conditions (**Fig. 3**). The subjects expended more energy during rototilling in untilled field than tilled field operation. The increase in forward speed resulted in the increase of energy expenditure of 9.1 to 10.20 percent when compared to the tilled field. The higher energy cost involved in untilled terrain might be due to the additional effort required by the subjects in walking and guiding the power tiller in soil with stubbles of previous crops. In addition, the bite of tynes of the rotary tiller on the relatively compacted terrain of untilled soil induces vibration, which might have increased the energy cost of the subjects. Therefore, the surface condition of the agricultural field was another factor contributing to operator's workload (Mamansari and Salokhe, 1999). The results clearly indicated that the energy expenditure of the subjects was influenced by the terrain conditions (Mc Ardle, 1994). Comparison between power tiller A and power tiller B clearly showed a marked difference in energy expenditure between the two power tillers as shown in **Fig. 3**. The mean energy expenditure of the subjects was higher for power tiller A than those for power tiller B in both untilled and tilled fields.

As power tiller B was provided with a seating attachment, the operator could comfortably sit and ride

Fig. 3 Energy cost of power tiller operations



the power tiller with little drudgery. But, in the walking type power tiller (Power tiller A), the subjects must walk during the entire period of operation. It is observed that operating the power tiller with aseating attachment saved human energy requirement to the tune of 23 to 30 percent with increase in forward speed from 1.5 to 2.4 km h^{-1} in untilled field and 18 to 25 percent in tilled field, respectively. The results clearly indicated that operation of power tiller without a seating attachment involved higher physiological cost in comparison to that with seating attachment. This confirmed the earlier results reported by Tiwari and Gite, 2000). The effect of terrain condition on energy cost of the subject was more pronounced in untilled field when compared to tilled field for both the power tillers.

The physiological response of the subjects during transport with walking type power tiller (A) and riding type power tiller (B) on farm roads and bitumen roads and grading of the work are furnished in **Table 2**.

Based on the mean energy expenditure, the operation was graded as "Light work" for all the selected levels of forward speed (Rodahl, 1989). The increase in energy cost was 17.27 percent as the forward speed increased from 1.5 to 2.4 km h^{-1}. Comparison of energy cost of work between farm road and bitumen road is shown in **Fig. 3**. The increase in energy expenditure was by 6.97 to 10.85 percent on farm road than bitumen road for the speed level from 3.5 to 5.0 km h^{-1}. This might be due to the more discomfort experienced by the subject while operating the power tiller on farm roads with undulations and surface roughness.

Comparison between power tillers A and B during transport with trailer showed that human energy requirement was higher for power tiller B when compared to power tiller A as depicted in **Fig. 3**. This might be due to the fact that maneuvering and handling of power tiller B was more difficult than power tiller A since the positioning of the handle and trailer seat with respect to engine was at a longer distance for power tiller B (1,850 and 2,270 mm) when compared to power tiller A (1,170 and 2,150 mm). Moreover the weight of power tiller B (517 kg) was more than power tiller A (442 kg). The subjects might have exerted more energy in handling the heavy weight power tiller B. It is observed that when compared to power tiller B, operating power tiller A with an empty trailer resulted in saving of human energy requirement to the tune of 15.33 to 16.23 percent on a farm road and 11.3 to 4.9 percent on a bitumen road with increase in forward speed from 3.5 to 5.0 km h^{-1}, respectively.

ii. Acceptable Workload (AWL)

The mean oxygen uptake of all operating conditions in terms of maximum aerobic capacity was calculated for all the subjects an d the values are furnished in **Table 3**. For field operation with the walking type power tiller the oxygen uptake in terms of VO_2 max varied from 35.30 to 43.93 percent which was above the acceptable work load whereas the values varied from 29.04 to 33.74 percent for riding type (8.95 kW) power tiller and was within the acceptable workload. During transport mode oxygen uptake in terms of VO_2 max varied from 22.24 to 28.03 percent and the values were within the acceptable limit of 35 percent of VO_2 max for both power tillers.

Table 3 Oxygen uptake interms of VO_2 max for power tiller operation

Operation	Power tiller	Maximam aerobic capacity of subjects, %				AWL, 35 % of VO_2 max
		Forward speed, km h^{-1}				
1. Rototilling		**1.5**	**1.8**	**2.1**	**2.4**	
Untilled field	A	37.45	39.32	41.57	43.93	> AWL
	B	30.50	31.68	32.78	33.74	< AWL
Tilled field	A	35.30	35.60	36.98	39.86	> AWL
	B	29.04	30.00	30.64	31.91	< AWL
2. Transport mode		**3.5**	**4.0**	**4.5**	**5.0**	
Farm road	A	22.96	23.81	25.43	26.44	< AWL
	B	26.48	27.03	27.75	28.03	< AWL
Bitumen road	A	22.24	24.09	24.16	25.65	< AWL
	B	24.75	24.38	24.97	25.52	< AWL

iii. Limit of Continuous Performance (LCP)

The increase in physiological responses over resting values of heart rate (Δ HR) for all the subjects at selected levels of forward speed for all selected operations were calculated and the values are furnished in **Table 4**.

It is observed that the work pulse (Δ HR) for all the operations at selected levels of forward speed varied from 21.08 to 37.79 percent during rototilling in untilled and tilled field respectively. It varied from 13.23 to 19.88 and 11.42 to 17.50 during transport operation on farm and bitumen road respectively. The work pulse values for power tiller B were lower than power tiller A both in untilled and tilled field. This confirmed the result that the seating arrangement provided in power tiller B enhanced the comfort of the subjects. It was observed that in all the selected operations, the work pulse values were well within the limit of continuous performance of 40 beats min^{-1} for both power tillers on a farm and a bitumen road.

Conclusions

Based of the analysis of results the

following conclusions were drawn.

- The basal metabolic rate of the selected three subjects varied form 1,402 to 2,005 kcal day^{-1}.
- The relationship between the heart rate and oxygen consumption of the subjects was found to be linear for all the subjects.
- The maximum aerobic capacity of the selected subjects varied from 1.98 to 2.48 L min^{-1}.
- For rototilling in untilled field the energy cost of work varied from 17.13 to 20.09 kJ min^{-1} for walking type (7.46 kW) power tiller and 13.95 to 15.43 kJ min^{-1} for riding type (8.95 kW) power tiller. In tilled field the values varied from 15.70 to 18.23 kJ min^{-1} and 13.28 to 14.59 kJ min^{-1}, respectively. The operations were generally graded as "moderate work".
- The rototilling operation in untilled field was strenuous as it demanded 9.1 to 10.20 percent and 1 to 6 percent more energy for walking type (7.46 kW) and riding type power tillers (8.95 kW), respectively, than in tilled field.
- Power tiller with seating attachment resulted in saving of 23 to 30 percent and 18 to 25 percent human energy requirement in untilled and tilled field, respectively.
- In transport mode the energy cost of work varied from 10.17 to 11.12 kJ min^{-1} and 11.32 to 12.82 kJ min^{-1} with the 7.46 kW and 8.95 kW power tillers, respectively. The operation was generally graded as "light work" to "moderate work".
- When compared to 8.95 kW power tiller, the 7.46 kW power tiller resulted in a saving of human energy requirement of 15.33 to 16.23 percent on a farm road and 4.9 to 11.3 percent on a bitumen road. The energy cost increased with increase in forward speed of operation.
- For field operation with walking type power tiller the oxygen uptake in terms of VO_2 max varied from 35.30 to 43.93 percent which was above the acceptable work load whereas the values varied from 29.04 to 33.74 percent for riding type (8.95 kW) power tiller and was within the acceptable workload.
- During transport mode oxygen uptake in terms of VO_2 max varied from 22.24 to 28.03 percent and the values were within the acceptable limit for both power tillers.
- The work pulse (Δ HR) varied from 21.08 to 37.79 percent for field operations and 11.42 to 19.88 for transporting operations and were within the limit of continuous performance.

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Table 4 Work pulse (Δ HR) for power tiller operation

Operation	Power tiller	Work pulse, beats min^{-1}				LCP, 40 beats min^{-1}
		Forward speed, km h^{-1}				
1. Rototilling		**1.5**	**1.8**	**2.1**	**2.4**	
Untilled field	A	32.25	34.79	37.24	37.79	< LCP
	B	21.08	24.92	24.86	25.21	< LCP
Tilled field	A	27.47	28.24	31.23	33.16	< LCP
	B	22.02	22.28	23.09	24.88	< LCP
2. Transport mode		**3.5**	**4.0**	**4.5**	**5.0**	
Farm road	A	13.29	13.23	17.46	18.71	< LCP
	B	18.81	19.35	19.52	19.88	< LCP
Bitumen road	A	11.42	15.13	13.67	17.50	< LCP
	B	16.14	16.06	16.96	16.78	< LCP