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Evaluation of Human Energy Consumption in Paddy Cultivation Practices

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

As the majority of the framers are small and marginal in India accounts for almost 85%, the farming practices are usually doing manually. These manual practices demand much energy consumption from the farmers which ultimately results in the reduced efficiency, productivity of work. The objective of the study is to evaluate the Energy Expenditure Rate (EER), Cardiac Cost of Work (CCW), Cardiac Cost of Recovery (CCR), Total Cardiac Cost of Work (TCCW), and Physiological Cost of Work (PCW) in paddy cultivation practices. Sample size of 10 per activity was taken for the present study in the East and West Godavari districts of Andhra Pradesh. For all the components

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(EER, CCW, CCR, TCCW, and PCW), heart rate was taken at three different intervals viz. resting phase, working phase, and recovery phase. Each activity in the paddy cultivation was standardized to five minutes. Results found that EER was found to be very high (180.71%), (183.11%) in transplanting activity and threshing activity among female-dominated and male-dominated activities respectively. Similarly, CCW (245bpm, 240bpm); CCR (57.85bpm, 56.62bpm); TCCW (302.85bpm, 296.62bpm); PCW (60.57bpm, 59.32bpm) values were found high in the threshing activity which ranked first among male dominated activities and transplanting activity among female dominated activities. It can be concluded that farmers can opt the tools that are less energy-demanding. Such type of tools is drum seeder, improved sickle, Dapog method of paddy transplanting, etc. Extension agents can suggest the farmers about improved tools that are at low operational cost and can give maximum efficiency and productivity.

Keywords: Energy consumption; productivity; efficiency.

1. INTRODUCTION

During the Green Revolution, the agricultural sector in India reached self-sufficiency by using better inputs such as high-yielding varieties (HYVs) and inorganic fertilizers. Since then, the agriculture sector had amazing expansion and now it has reached a substantial worldwide footprint in terms of the production of important staple foods like rice, wheat, milk, sugarcane, fruits, and vegetables. Indian agriculture suffers from the paradox of 'Grain Mountains and Hungry Millions' [1]. Currently, rice is grown on 43.79 million hectares (Mha) of cultivated land in India, with a production of 116.4 million tons (Mt) [2]. It is essential to ensure that farmers' incomes are expanded to be commensurate with their efforts and investments. Almost all the cultivation practices in the paddy production system were practiced manually by farmers because the majority of farmers in India are small and marginal, so not in a position to mechanize land for agricultural practices. Cultivation of rice involves many activities that require great physical effort including ploughing the field, uprooting the seedlings from the nursery, planting the saplings in the main field, fertilizer application, harvesting, threshing, and winnowing.

According to Varghese's [3] classification, Weeding is a strenuous activity as it is heavy activity, physiological cost, and energy expenditure are very high, and Moderate to very severe pain was observed in the lower back, upper back, neck, shoulder, knee, and wrists if done manually. Nawi et.al., [4] done a study to evaluate the human energy consumption of various cultivation practices involved in lowland rice cultivation in Malaysia. Based on recorded average heart rates, fertilizer application was found to be the most strenuous operation, with an average heart rate of 138 beats min^{-1}. There were no significant differences in the average heart rates of the farmers among the individual tasks within the very first ploughing, second ploughing, and harvesting operations, with the average heart rates for these three tasks being 116, 106, and 106 beats min^{-1}, respectively. The energy expenditures were 3.90, 3.43, and 3.35 kcal min^{-1}. filling the seed into the blower tank and broadcasting the seed were regarded as the most critical tasks for the seed broadcasting operation, with average heart rates of 124 and 136 beats min^{-1}, respectively. The highest energy expenditure of 418.38 kcal ha^{-1} was reported for seed broadcasting, and the lowest energy expenditure of 127.96 kcal $ha^{-1}$was reported for second ploughing. The total seasonal human energy expenditure for rice cultivation was estimated to be 5810.71 kcal ha^{-1}, 55.7 percent of which has been spent on pesticidal spray. Though the sample size in the study was relatively small, the results showed that human energy expenditure per unit area (kcal ha^{-1}) was positively linked to the average heart rate of the farmers and negatively linked to the field capacity. Anita et.al., [5-7] revealed that among the four traditional agricultural activities, a maximum average heart rate of 107.8 beats min^{-1} was observed while farmers performing weeding with traditionally available tools, and among the activities with improved implements, use of long handle weeder in vegetable cultivation recorded the maximum average heart rate of 101.8 beats min^{-1}, followed by use of sapling transplanter for transplanting of tomato recorded the average heart rate of 97.6 beats min^{-1}.

2. SAMPLING PLAN

The present study was done in the two highest paddy producing districts in Andhra Pradesh

List 1. Classification of workload [8]

Physical workload	Physiological parameters	
	Energy Expenditure (KJ/min)	Heartbeats (beats/min)
Very light	Up to 5.0	Up to 90
Light	5.0-7.5	91-105
Moderate	7.6-10.0	106-120
Heavy	10.0-12.5	121-135
Very Heavy	12.6-15.0	136-150
Extremely Heavy	<15.0	Above 151

namely East Godavari and West Godavari. From each district 10 samples were taken randomly includes 5 males and 5 females which constitute 20 samples from two districts for each activity in paddy cultivation for present study.

3. MATERIALS AND METHODS

For EER, Heartbeat was taken as the parameter and it was taken at three different intervals which yields the percentage increase in the Energy Expenditure from the resting phase to the working phase in the particular activity. Each activity was standardized for five minutes. Sample size is 10 for each activity and includes both males and females. Present study was carried out in west and east Godavari districts of Andhra Pradesh. Results were presented separately for both the males and females according to the activities they performed.

3.1 Energy Expenditure (EE)

EE calculated using the following formula [3]

Energy expenditure (kJ/min) = 0.159 x Heart rate at resting phase(beats/min) – 8.72;

0.159 x Heart rate at working phase(beats/min) – 8.72; 0.159 x Heart rate at recovery

phase(beats/min) – 8.72. [3]

3.2 Cardiac Cost of Work (CCW)

$$CCW = \Delta HR. tA$$

Where, CCW = Cardiac Cost of Work, Δ HR = Mean Working Heart Rate – Mean Resting Heart Rate, tA = Duration of Activity

3.3 Cardiac Cost of Recovery (CCR)

CCR = (AHR recovery – AHR rest). tR

Where, CCR = Cardiac Cost of Work, AHR recovery = Average Recovery Heart Rate,

AHR rest = Average Resting Heart Rate, tR = Duration of Recovery.

3.4 Total Cardiac Cost of Work (TCCW)

$$TCCW = CCW + CCR$$

Where, CCW = Total Cardiac Cost of Work, CCR= Cardiac Cost of Recovery

3.5 Physiological Cost of Work (PCW)

$$PCW = TCCW/tA$$

Where, TCCW = Total Cardiac Cost of Work, tA = Duration of activity

4. RESULTS AND DISCUSSION

4.1 Energy Expenditure Rate (EER)

For EER, Heartbeat was taken as the parameter and it was taken at three different times in a time-bound activity viz, Working phase, Resting phase, and finally Recovery phase. EER is the percentage change in the energy in Kilo Joules per minute from the resting phase to the working phase. Each activity was standardized for five minutes with a sample size of 10 was taken for each activity.

From the above Table 1, it was concluded that EER in the threshing activity was found to be very high (183.11 percent) which indicates that it was the most energy-demanding activity in paddy cultivation practices. So threshing activity stood first. Followed by manure and fertilizer application activity (170.60 percent), Pesticidal spray (168.67 percent), Land preparation (143.84 percent), and Irrigation (142.71 percent) which were ranked second, third, fourth, and fifth respectively.

Table 1. Energy expenditure rate values in the paddy cultivation practices done by male farmers (N=10)

Activities	Resting phase (KJ/min)	Working phase (KJ/min)	Energy Expenditure (EE) (KJ/min) (Mean and SD)	Percent change in EER per minute	Interpretation w.r.t. physical load
Land preparation	4.04	9.87	20.27(±0.87)	143.84%	Extremely Heavy
Irrigation	4.33	10.52	20.00(±2.12)	142.71%	Extremely Heavy
Manure and fertilizer application	4.28	11.59	20.67(±1.87)	170.6%	Extremely Heavy
Pesticidal spray	4.17	11.21	20.89(±1.10)	168.67%	Extremely Heavy
Threshing	4.29	12.14	22.43(±0.92)	183.11%	Extremely Heavy

Table 2. Energy expenditure rate values in the paddy cultivation practices done by female farmers (N=10)

Activities	Resting phase (KJ/min)	Working phase (KJ/min)	Energy Expenditure (EE) (KJ/min) (Mean and SD)	Percent change in EER per minute	Interpretation w.r.t. physical load
Uprooting	4.27	10.02	19.93(±1.30)	134.78%	Extremely Heavy
Transplanting	4.33	12.16	23.00(±0.79)	180.71%	Extremely Heavy
Weeding	4.13	11.17	21.29(±0.88)	170.28%	Extremely Heavy
Harvesting	4.14	11.53	22.61(±1.42)	178.26%	Extremely Heavy
Winnowing	4.19	10.82	21.29(±1.30)	158.37%	Extremely Heavy

From the above Table 2, it was concluded that EER in the transplanting activity was found to be very high (180.71 percent) which indicates that it was the most energy-demanding activity in paddy cultivation practices. So, transplanting activity stood first. Followed by harvesting activity (178.26 percent), weeding (170.28 percent), winnowing (158.37 percent), and uprooting (134.78 percent) which were ranked second, third, fourth, and fifth respectively.

4.2 Cardiac Cost of Work (CCW)

It was observed from Table 4 that CCW values in the threshing activity among male farmers were found to be high (245 bpm) which ranked first followed by pesticidal spray (216 bpm), manure and fertilizer application (215 bpm), land preparation (198 bpm), and irrigation (190 bpm) activities ranked second, third, fourth, and fifth respectively.

It was observed from above Table 5 that CCW values in the transplanting activity among female farmers found to be high (240 bpm) which ranked first followed by harvesting (226 bpm), weeding (208 bpm), winnowing (199 bpm), and uprooting (181 bpm) activities ranked second, third, fourth, and fifth respectively.

4.3 Cardiac Cost of Recovery (CCR)

From the Table 6, it was concluded that CCR values in the activities done by male farmers have been found that threshing (57.85 bpm) ranked first followed by pesticidal spray (37.80 bpm), land preparation (36.45 bpm), Manure and fertilizer application (33.48 bpm), and irrigation activities (28.8 bpm) which were ranked second, third, fourth, and fifth respectively.

From the Table 7 it was concluded that CCR values in the activities done by female farmers have been found that transplanting activity (56.62 bpm) ranked first followed by harvesting (53.64 bpm), weeding (40.60 bpm), Winnowing (39.30 bpm), and uprooting activities (30.1 bpm) which were ranked second, third, fourth, and fifth respectively.

Table 3. Cardiac cost of work values in the paddy cultivation practices done by male farmers (N=10)

Activities done by male farmers	Cardiac Cost of Work (CCW) in beats/minute (Mean and SD)
Land preparation	198 (±15)
Irrigation	190 (±11)
Manure and fertilizer application	215 (±19)
Pesticidal spray	216 (±16)
Threshing	245 (±21)

Table 4. Cardiac cost of work values in the paddy cultivation practices done by female farmers (N=10)

Activities done by female farmers	Cardiac Cost of Work (CCW) in beats/minute (Mean and SD)
Uprooting	181(±14)
Transplanting	240(±22)
Weeding	208(±16)
Harvesting	226(±18)
Winnowing	199(±11)

Table 5. Cardiac cost of recovery values in the paddy cultivation practices done by male farmers (N=10)

Activities done by male farmers	Cardiac Cost of Recovery values in beats/min (Mean and SD)
Land preparation	36.45(±2.3)
Irrigation	28.8(±1.7)
Manure and fertilizer application	33.48(±2.1)
Pesticidal spray	37.8(±3.4)
Threshing	57.85(±4.8)

Table 6. Cardiac cost of recovery values in the paddy cultivation practices done by female farmers (N=10)

Activities done by female farmers	Cardiac Cost of Recovery values in beats/min (Mean and SD)
Uprooting	30.1(±1.6)
Transplanting	56.62(±4.7)
Weeding	40.6(±2.9)
Harvesting	53.64(±3.7)
Winnowing	39.3(±1.8)

Table 7. Total cardiac cost of work values in the paddy cultivation practices done by male farmers (N=10)

Activities done by male farmers	Total Cardiac Cost of Work values in beats/min (Mean and SD)
Land preparation	234.45 (±31.3)
Irrigation	218.8 (±19.3)
Manure and fertilizer application	248.48 (±22.4)
Pesticidal spray	253.8 (±23.6)
Threshing	302.85 (±18.1)

Table 8. Total cardiac cost of work values in the paddy cultivation practices done by female farmers (N=10)

Activities done by female farmers	Total Cardiac Cost of Work values in beats/min (Mean and SD)
Uprooting	211.1(±13.1)
Transplanting	296.62(±19.6)
Weeding	248.60(±22.1)
Harvesting	279.64(±17.9)
Winnowing	238.30(±19.4)

Table 9. Physiological cost of work values in the paddy cultivation practices done by male farmers (N=10)

Activities done by male farmers	Physiological Cost of Work values in beats/min (Mean and SD)
Land preparation	46.89(±3.9)
Irrigation	43.76(±4.1)
Manure and fertilizer application	49.69(±3.8)
Pesticidal spray	50.76(±5.2)
Threshing	60.57(±4.9)

Table 10. Physiological cost of work values in the paddy cultivation practices done by female farmers (N=10)

Activities done by female farmers	Physiological Cost of Work values in beats/min (Mean and SD)
Uprooting	42.22(±4.1)
Transplanting	59.32(±4.6)
Weeding	49.72(±39)
Harvesting	55.92(±5.3)
Winnowing	47.66(±2.7)

4.4 Total Cardiac Cost of Work (TCCW)

From the Table 8 it was concluded that TCCW values in activities done by male farmers have been found that threshing (302.85 bpm) ranked first followed by pesticidal spray (253.8 bpm), manure and fertilizer application (248.48 bpm), land preparation (234.45 bpm), and irrigation activities (218.8 bpm) which were ranked second, third, fourth, and fifth respectively.

From the Table 9 it was concluded that TCCW values in activities done by female farmers have been found that transplanting activity (296.62 bpm) ranked first followed by harvesting (279.64 bpm), weeding (248.60 bpm), Winnowing (238.30 bpm), and uprooting activities (211.1 bpm) which were ranked second, third, fourth, and fifth respectively.

4.5 Physiological Cost of Work (PCW)

From the Table 10, it was concluded that PCW values in activities done by male farmers have been found that threshing (60.57 bpm) ranked first followed by pesticidal spray (50.76 bpm), manure and fertilizer application (49.69 bpm), land preparation (46.89 bpm), and irrigation activities (43.76 bpm) which were ranked second, third, fourth, and fifth respectively.

From the Table 10, it was concluded that PCW values in activities done by female farmers have been found that transplanting activity (59.32 bpm) ranked first followed by harvesting (55.92 bpm), weeding (49.72 bpm), Winnowing (47.66 bpm), and uprooting activities (42.22 bpm) which were ranked second, third, fourth, and fifth respectively.

5. DISCUSSION

The physiological workload of a worker can majorly be reduced using a conoweeder for wetland paddy crops, The physiological cost of work and energy expenditure of respondents was 10.36 beats min^{-1} and 7.50 Kj min^{-1} respectively against 19.83 and 10.82 if done manually [9-11]. Mechanization of some tasks could drastically decrease worker physical effort and fatigue and thereby increase production [4,12-14].

6. CONCLUSION AND WAY FORWARD

All the cultivation practices in paddy were found to be very difficult to do. If the farmers continue to do the practices manually, it leads to various health hazards which ultimately results in the reduction of efficiency and productivity of the work. There is a need to conduct the extension programmes, campaigns with the special attention to the drudgery involved cultivation practices. Extension agents should make the farmers aware of improved tools available for the paddy cultivation practices such as improved sickle, weeder, transplanter etc. which helps in reduced energy consumption in doing the cultivation practices.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

CONSENT

Data was collected with the informed consent of the framers.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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