https://doi.org/10.17221/23/2021-RAE

Cost analysis of manual bund shaping in paddy fields: Economical and physiological

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Citation: Ranjan R., Pranav P.K. (2021): Cost analysis of manual bund shaping in paddy fields: Economical and physiological. Res. Agr. Eng., 67: 181–189.

Abstract: Bund shaping is one of the essential operations in preparing a paddy transplanting field. This operation is undertaken manually by spades in a traditional way as this has not been mechanised thus far. Therefore, this study was conducted to expose this operation by evaluating the economic, as well as physiological, cost involved in the bund shaping. For the economic cost, the study was conducted in nine different districts of Assam (India). The bund length for the estimated area was measured and estimated for one ha of land. The average rate of manual bund shaping was also measured to calculate the cost involved in this operation. Moreover, for the physiological cost, ten experienced subjects were calibrated and measured for their maximum aerobic capacity by sub-maximal exercise in laboratory condition. Furthermore, the heart rate was measured during the manual bund shaping and was then correlated with the calibrated data. It was found that the average required bund shaping length per ha was 3 669 m which was associated with a cost of 2 062.8 rupees. It was found that the bund shaping consumed 76.96% of the maximum volume of the oxygen consumption capacity of the subjects; however, the energy expenditure rate with respect to time and bund length were 7.37 kcal·min^{-1} and 4.33 kcal·m^{-1}, respectively. Hence, bund shaping in a paddy field comes under a severe workload category which emphasises the need of mechanisation for the bund shaping operation.

Keywords: cost of operation; economic cost; heart rate; paddy field; subject calibration; work severity

Paddy rice is one of the mostly grown staple foods in India covering 43.86 million ha of land resulting in the production of 104.80 million tonnes with productivity about 2 390 kg·ha^{-1} (Government of India 2015). The field preparation for paddy cultivation is one of the most important operations responsible for its high production. The field preparation has been mechanised nowadays mainly due to the easy availability of power tillers as well as their matching implements. A field preparation also consists of an operation called bund shaping in the paddy field which is carried out at the beginning of each paddy season. During a field survey, it was found that the bund shaping is carried out manually using a spade in the traditional way. Bunds becomes distorted and undulated due to the growth of unwanted weeds, the traffic of humans, animals and agricultural machinery and the overflow of excess water over the bunds. These bunds need to be shaped into uniform sizes with a desirable height and are well plastered with mud to eliminate any holes. The plastering of bunds also helps in reducing a weed infestation. A proper shaped bund helps in keeping the field under ponding conditions during the rainy season and reduces seepage loss. Bund shaping also helps in the optimal field utilisa-

Supported by the ICAR, New Delhi for providing financial support to carry out this research.

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tion and provides favourable conditions needed for the puddling action.

As per an Indian census, about 75% of the total human workforce is involved in agricultural activities which led researchers (Pranav and Biswas 2016; Pranav and Patel 2016; Rajaiah et al. 2016; Khadatkar et al. 2018) to study various farm operations to suggest safe and comfortable work environments for the workers. Especially for paddy cultivation, Baqui and Latin (1982), Karunanithi and Tajuddin (2003), Singh (2009), Selvan et al. (2014), Ojha and Kwatra (2017) worked on transplanting/sowing, Singh et al. (1985), Kathirvel et al. (2004), Ghosh et al. (2016) studied on weeding/spraying and Nag et al. (1988), Ghugare et al. (1991), Singh et al. (2004), Singh and Gite (2007), Bini (2014), Tang et al. (2017) worked on harvesting/threshing along with many others. The bund shaping operation has remained unevaluated except for a study by Nag and Nag (2004) who reported that energy demand in bund trimming in wetland and dryland conditions is 19.6–35.5 $kJ\cdot min^{-1}$. In one other study (Nag et al. 1980), it was reported that wetland and dryland conditions of bund trimming requires 63.5 and 80.8% VO_{2max} based on a study on thirteen subjects, respectively. The data indicated that bund shaping falls under an extreme heavy work category, but it was not validated against subjects of other regions.

Therefore, a study was taken in order to analyse the economic and physiological cost of manual bund shaping in a paddy field in the state of Assam, India.

MATERIAL AND METHODS

Economic cost. The economic cost mainly includes the cost of the manual bund shaping before the paddy transplanting which depends upon the length of the bund per unit area of cultivable land. The study data was collected from nine different districts namely: Dhemaji, Sivasagar, Charaideo, Lakhimpur, Biswanath, Nagaon, Golaghat, Jorhat and Dibrugarh of Assam. Three villages from each district were selected for the data collection.

The paddy cultivated fields were selected randomly where a minimum of 1 ha of paddy were cultivated in the previous cropping season. Before taking the measurement of such fields, a simple walk-through survey was conducted in the paddy field in order to look for a uniform field size, i.e. basically free from sharp undulations, any unnecessary deep trench, bund or slope. Subsequently, permission from the field owner was also obtained. The owners were also explained about the usefulness of the study. The bund length per ha of land was calculated using the following procedure:

After the walk-through survey, the biggest field was identified, and a point 'P' was marked in one corner of the field where two adjacent edges are approximately perpendicular. From point P, a 100 m rope was laid out and the adjoining sides were marked on each side.

A sample view indicating the method for the measurement of the bund length per ha is shown in Figure 1.

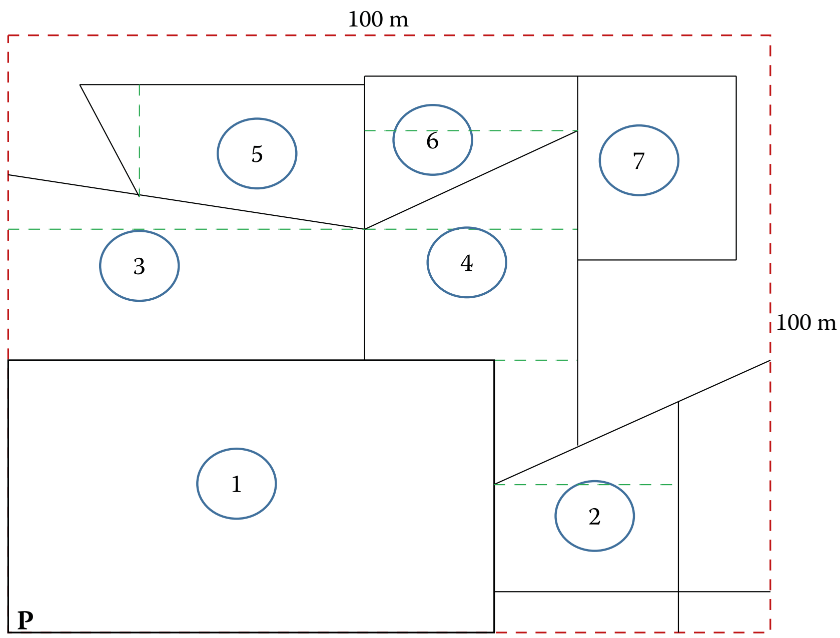

Figure 1. Sample representation of a paddy field with dimensions

Red colour dotted lines indicating 100 m × 100 m square field; black colour continous lines are the periphery of actual field; green colour of dotted lines for dividing the field in known shapes for area calculation

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The total number of complete fields within the periphery of the 100 m × 100 m square were counted and marked 1, 2, 3, and so on.

The actual dimensions of these fields were taken using a measuring tape and a drawing of these fields was made on the field notebook. The area of these fields was calculated by dividing the fields into imaginary squares, rectangles, trapezoidal and triangular shapes for ease of the calculation. The peripheral lengths of these fields were also calculated using the measured dimensions. The total bund length per ha (B_L) was calculated as the total length of the bund (L) divided by the total calculated area of these fields. Hence, the length of the bund to be shaped before transplanting was calculated by ($2 \times B_L - 400$ m) considering both the side bund shaping except for the outer side of the selected field.

Furthermore, the rate of bund shaping by manual labour using a spade in these districts was also measured. Bund shaping is heavy work for which workers need to take frequent rest in between. The length of the bund shaping in two hours was recorded including the rest time. The work rate was calculated considering a work period for six hours a day.

The cost of bund shaping was calculated considering the labour wage as 300 rupees (Rs.) per day (6 h per day).

Physiological cost. Under the physiological costs, the subjects were selected, and their heart rates were measured during the manual bund shaping operation. Beforehand, the selected subjects were calibrated in the laboratory to their known maximum aerobic capacity as well as to establish the relationship between the heart rate and oxygen consumption. The established relationship was used to obtain the desired oxygen consumption value during the spading operation in the bund shaping. This oxygen consumption was used to calculate the energy expenditure of the worker involved in this operation.

Selection of the subjects. A total of ten medically fit male subjects in the age group of 20–55 years were selected purposefully for the study from Lakhimpur district, Assam. All the subjects were selected from one district for ease of access because the work rate of subjects among the different selected districts was observed to be non-significant. The subjects, who were involved in the bund shaping operation for the paddy fields, were randomly selected. The demographic information such as age (years), stature (cm), body weight (kg) and resting heart rate (beats·min^{-1}) were recorded and are shown in Table 1.

The selected subjects were free from any muscular and cardio-vascular abnormalities and had at least 5 years of traditional bund shaping operation experience. The subjects were acquainted with the experimental protocol to enlist their full cooperation throughout the experiment.

Calibration of the subject. Calibrating the subject is a process of measuring the heart rate and oxygen consumption of a subject to establish a heart rate-VO_2 relationship for the subject. The selected subjects were calibrated under controlled environmental conditions. The subjects were given ample time to familiarise themselves with the treadmill and the instruments used in the experiment.

Table 1. Physical characteristics of the selected subjects

Subject	Age (years)	Weight (kg)	Stature (cm)	BMI	BSA (m^2)	Experience (years)	Resting heart beat (beats·min^{-1})
S1	36	57	162	21.7	1.6	20	87
S2	42	58	168	20.5	1.6	27	82
S3	40	53	170	18.3	1.6	25	74
S4	36	65	164	24.2	1.7	16	71
S5	43	66	161	25.5	1.7	22	84
S6	48	50	155	20.8	1.5	26	66
S7	39	62	168	22.0	1.7	12	76
S8	46	48	156	19.7	1.4	21	63
S9	37	56	165	20.6	1.6	11	69
S10	50	52	166	18.9	1.5	18	67
Mean	41.7	56.7	163.5	21.2	1.6	19.8	73.9
SD	4.75	5.84	4.78	2.2	0.1	5.28	7.77

BMI – body mass index; BSA – body surface area

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Figure 2. Calibration of the subject in the laboratory

The exercise was performed on a motor driven treadmill (Trackmaster TMX425). Before using the K4b2 (COSMED), the system was warmed up for at least 45 minutes (as required). This portable unit was calibrated for the delay, turbine and gas before calibrating a subject. For the gas calibration, the cylinder had a composition of 4.95% of carbon dioxide (CO_2), 16.05% of oxygen (O_2) and rest was made up of nitrogen. The results of the calibration were within the acceptable range.

After conducting these calibrations, a sub-maximal test was performed to determine the maximum aerobic capacity of the selected subjects following the Naughton protocol (Naughton et al. 1963). Each subject was allowed to walk on a treadmill and an incremental load (in term of speed and inclination) was applied at an interval of 3 minutes (Figure 2).

The experiment was continued till the heart rate reached 75% of the maximum heart rate (HR_{max}) which was calculated using the Robergs and Landwehr (2002) Equation (1):

$$HR_{max} = 205.8 - 0.685 \times \text{age} \quad (1)$$

The *HR* and VO_2 were recorded and a regression equation was developed. The developed regression equation is known as the calibration curve for the subject which was used to estimate the VO_2 with reference to the measured *HR* in the field. Furthermore, the calibration curve was extrapolated till the maximum heart rate was achieved. The extrapolated VO_2 corresponding to the HR_{max} was considered as VO_{2max}. A sample of the extrapolated curve between the *HR* and VO_2 for calculating VO_{2max} is shown in Figure 3.

The subject calibration equation, their HR_{max} and VO_{2max} are given in Table 2. The average HR_{max} and VO_{2max} were found to be 177.2 bpm and 35.99 mL·kg^{-1}·min^{-1}, respectively.

Measurement of HR in the field. The heart rates of the selected subjects were recorded by a heart rate monitor (Polar Rs 400) with a wrist band. The heart rate was measured during the manual bund shap-

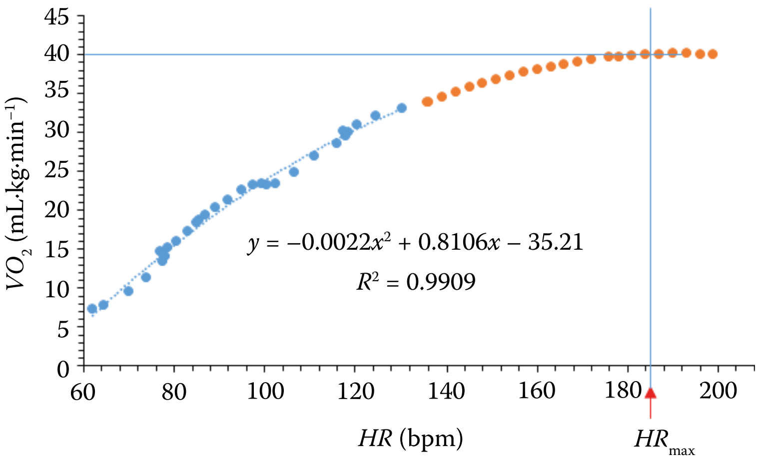

Figure 3. A sample curve plotted between *HR* and VO_2 for sub-maximal exercise

HR – heart rate; VO_2 – calculated volume of oxygen consumption

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ing in the field as shown in Figure 4. The data were taken for 30 min and during this period, the length of the bund shape was also recorded. Prior to the experiment, a rest period of 5–10 min was applied to bring the heart rate to the normal range. After the experiment, a rest period was given until the heart rate reached the normal value. The sample curve of the heart rate versus time during the bund shaping is shown in Figure 5. From the recorded average working heart rate, the volume of the oxygen consumption was estimated using the calibration curve.

Furthermore, the energy consumption during the manual bund shaping (energy expenditure rate) was calculated using Equation (2).

$$EER\ (\text{kcal}\cdot\text{min}^{-1}) = (O_2 \text{ consumption in L} \times 4.8) \quad (2)$$

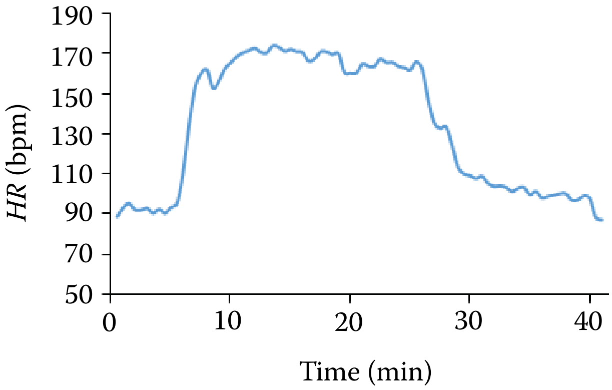

Figure 5. A sample curve of *HR vs.* time recorded during field work

HR – heart rate

Table 2. Subject wise calibration curve with HR_{max} and VO_{2max}

Subject	Calibration equation	R^2 value	HR_{max} (bpm)	VO_{2max} (mL·kg^{-1}·min^{-1})
S1	$y = -0.0017x^2 + 0.7562x - 47.452$	$R^2 = 0.9933$	181	33.73
S2	$y = -0.0014x^2 + 0.7473x - 48.554$	$R^2 = 0.9726$	177	39.86
S3	$y = -0.0021x^2 + 0.8082x - 40.695$	$R^2 = 0.9776$	178	36.63
S4	$y = -0.0008x^2 + 0.5289x - 32.383$	$R^2 = 0.9948$	181	37.13
S5	$y = -0.0018x^2 + 0.7793x - 48.704$	$R^2 = 0.9924$	176	35.92
S6	$y = -0.0002x^2 + 0.2216x - 7.484$	$R^2 = 0.9859$	173	36.84
S7	$y = -0.0025x^2 + 0.9292x - 52.449$	$R^2 = 0.9774$	179	33.78
S8	$y = -0.0022x^2 + 0.8106x - 35.21$	$R^2 = 0.9909$	174	39.24
S9	$y = -0.0033x^2 + 1.0752x - 55.545$	$R^2 = 0.9923$	181	31.02
S10	$y = -0.0026x^2 + 0.8917x - 40.665$	$R^2 = 0.9676$	172	35.78
Mean			177.20	35.99
SD			3.21	2.50

HR_{max} – maximum heart rate; VO_{2max} – maximum volume of oxygen consumption

Figure 4. *HR* measurement during manual bund shaping

HR – heart rate

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RESULTS AND DISCUSSION

The results of the study have been divided into two sections, namely the economic cost and the physiological cost.

Observations for the economic cost. The observed and calculated data that are used to present the economics involved in the bund shaping operations are presented in Table 3. The table clearly indicates that the bund length per ha is proportional to the number of bunds, which can be seen in Figure 6. The analysis of the data shows that the average size of the plot was 1 354.3 m^2 with a standard deviation of 364.5 m^2.

The data also revealed that the average cost of the bund shaping is Rs. 2 062.8 per ha with a standard deviation of Rs. 490. The minimum and maximum cost of bund shaping was observed to be Rs. 1 201.5 and 3 075.6 per ha in the Dibrugarh and Charaideo districts, respectively. A significant difference among the districts was observed because the number of plots in one ha of land only as the work rate of worker is non-significant. The work rate of the workers varied between 167.40 m to 188.10 m per two hours. The district-wise cost of the bund shaping with respect to the bund shaping length and average plot area is presented in Figure 7.

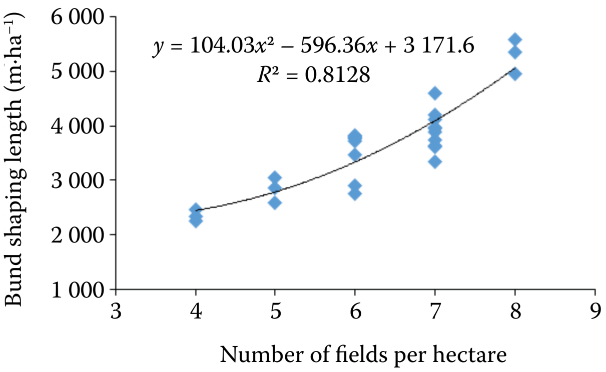

Figure 6. Bund length a hectare with respect to the number of fields

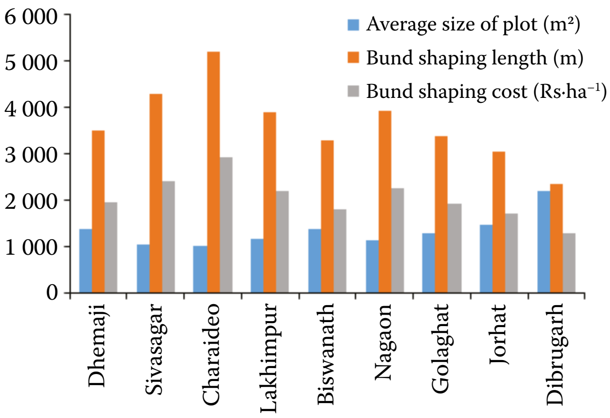

Figure 7. Graphical representation of economic data in different districts of Assam

Furthermore, it was observed from the Shapiro-Wilk test that the bund shaping rate by the workers from the different districts of Assam are normally distributed as a P-value of more than 0.05 and is shown in Figure 8. This clearly indicated that the physiological test on any set of workers would be the representative data for the entire state.

Observation of the physiological cost. The measured HR, calculated volume of oxygen consumption (VO_2) and corresponding EER during the manual bund shaping are given in Table 4.

It was found that the average resting and working HR during the bund shaping process were found to be 74 and 133 bpm, respectively. Furthermore, the corresponding VO_2 and EER values during the manual bund shaping were calculated as 27.29 mL·kg^{-1}·min^{-1} and 7.37 kcal·min^{-1}, respectively. The percentage of the VO_{2max} consumed by the labour during the manual bund shaping was 76.69% which is considered to be very high. A similar observation was also observed by Nag et al. (1980). The average energy required (ER_M) for the bund shaping was found to be 4.33 kcal per metre of the bund. The average working HR of subjects S10 and S2 is much higher than the other subjects, which may be because of their faster pace of operation. The average energy per ha required (ER_H) in the bund shaping was found to be 77 704.66 kcal·ha^{-1}.

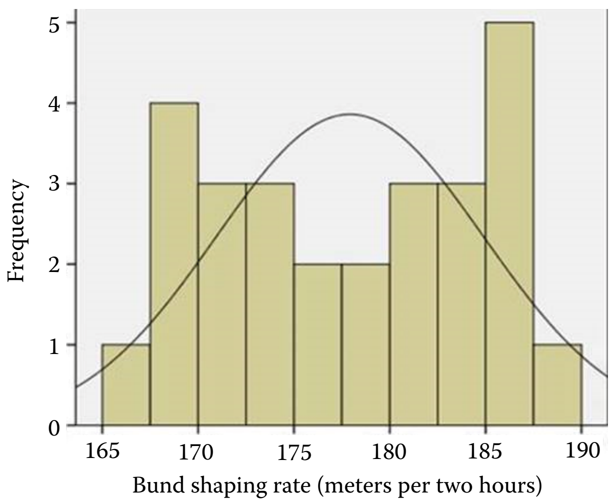

Figure 8. Normal distribution of bund shaping rate of worker among districts

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Table 3. Economic data in manual bund shaping of paddy field

Name of districts	Village	No. of complete plot in 100 m × 100 m demarcated area	Area (m^2)	Bund length (m)	Bund length (meters per ha)	Bund shaping length (m)	Bund shaping rate (m per two hour)	Cost of bund shaping ($Rs·ha^{-1}$)
Dhemaji	1	5	0.83	1 358.05	1 636.20	2 872.41	174.70	1 644.2
	2	6	0.74	1 562.10	2 110.95	3 821.89	186.70	2 047.1
	3	6	0.76	1 593.60	2 096.84	3 793.68	172.30	2 201.8
Sivasagar	1	7	0.72	1 657.25	2 301.74	4 203.47	183.90	2 285.7
	2	8	0.75	2 004.50	2 672.67	4 945.33	177.40	2 787.7
	3	7	0.84	1 742.90	2 074.88	3 749.76	172.60	2 172.5
Charaideo	1	8	0.71	2 044.00	2 878.87	5 357.75	174.20	3 075.6
	2	8	0.81	2 424.40	2 993.09	5 586.17	187.10	2 985.7
	3	7	0.78	1 948.60	2 498.21	4 596.41	167.40	2 745.8
Lakhimpur	1	7	0.76	1 664.70	2 190.39	3 980.79	178.80	2 226.4
	2	6	0.74	1 536.60	2 076.49	3 752.97	182.70	2 054.2
	3	7	0.79	1 721.60	2 179.24	3 958.48	169.00	2 342.3
Biswanath	1	5	0.79	1 364.70	1 727.47	3 054.94	171.10	1 785.5
	2	6	0.79	1 525.20	1 930.63	3 461.27	186.40	1 856.9
	3	7	0.88	1 644.45	1 868.69	3 337.39	186.60	1788.5
Nagaon	1	6	0.72	1 486.70	2 064.86	3 729.72	169.00	2 206.9
	2	7	0.80	1 715.80	2 144.75	3 889.50	167.60	2 320.7
	3	7	0.74	1 671.20	2 258.38	4 116.76	187.40	2 196.8
Golaghat	1	7	0.89	1 798.80	2 021.12	3 642.25	179.50	2 029.1
	2	7	0.84	1 687.20	2 008.57	3 617.14	170.50	2 121.5
	3	6	0.84	1 389.60	1 654.29	2 908.57	181.80	1 599.9
Jorhat	1	6	0.71	1 482.00	2 087.32	3 774.65	169.20	2 230.9
	2	6	0.87	1 370.60	1 575.40	2 750.80	180.20	1 526.5
	3	5	0.87	1 298.70	1 492.76	2 585.52	182.90	1 413.6
Dibrugarh	1	4	0.84	1 200.90	1 429.64	2 459.29	175.40	1 402.1
	2	4	0.88	1 170.40	1 330.00	2 260.00	188.10	1 201.5
	3	4	0.90	1 236.60	1 374.00	2 348.00	181.30	1 295.1
Minimum		4.00	0.71	1 170.40	1 330.00	2 260.00	167.40	1 201.5
Maximum		8.00	0.90	2 424.40	2 993.09	5 586.17	188.10	3 075.6
Average		6.24	0.80	1 617.10	2 034.50	3 669.00	177.91	2 062.8
SD		1.16	0.06	283.33	424.57	849.15	6.98	490.4

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Table 4. Measured *HR* and corresponding value of energy for field operation

Subject	Measured value			Calculated value				
	HR_{rest} (bpm)	HR_{work} (bpm)	Work rate (m·min^{-1})	VO_2 (mL·kg^{-1}·min^{-1})	% of VO_{2max}	*EER* (kcal·min^{-1})	ER_M (kcal·m^{-1})	ER_H (kcal·ha^{-1})
S1	87	121	0.95	19.16	56.81	5.24	5.52	99 059.22
S2	82	144	1.50	31.05	82.84	8.20	5.46	97 982.48
S3	74	137	2.29	30.61	83.52	7.79	3.40	61 014.73
S4	71	142	2.14	26.59	71.59	8.30	3.88	69 628.58
S5	84	132	1.53	22.80	63.47	7.22	4.72	84 702.81
S6	66	124	1.50	23.07	62.62	5.54	3.69	66 218.93
S7	76	142	2.27	29.09	86.11	8.66	3.81	68 372.39
S8	63	110	1.93	27.34	69.66	6.30	3.26	58 502.36
S9	69	137	1.97	29.82	96.13	8.02	4.07	73 038.23
S10	67	143	1.53	33.37	94.11	8.41	5.49	98 520.85
Mean	73.90	133.20	1.76	27.29	76.69	7.37	4.33	77 704.06
SD	8.20	11.40	0.43	4.43	13.74	1.25	0.89	15 174.94

HR_{rest} – resting heart rate; HR_{work} – working heart rate; VO_2 – calculated volume of O_2 consumption; VO_{2max} – maximum VO_2 corresponding to the maximum *HR*; *EER* – energy expenditure rate; ER_M – energy required per metre; ER_H – energy required per hectare

CONCLUSION

From the study, it can be concluded that a significant amount of cost (Rs. 2 063 per ha) is involved in the bund shaping. The cost is directly proportional to the number of plots per ha of land. Hence, the bund shaping cost was higher for small and fragmented plots. Furthermore, the physiological study indicated that the bund shaping operation demands 77% of the worker's maximum aerobic capacity and, hence, this operation falls under a severe workload. The overall study concludes that bund shaping is expensive as well as being laborious which demands the future mechanisation of the bund shaping operation for paddy fields.

Acknowledgement: Authors are very much thankful to Dr. K.N. Agrawal, the project coordinator of "All India coordinate research project on ergonomics and safety in agriculture" for his valuable suggestions time to time.

REFERENCES

Baqui A., Latin R.M. (1982): Human energy expenditure in manually operated rice transplanter. Agricultural Mechanization in Asia, Africa and Latin America, 14: 14–16.

Bini S. (2014): Ergonomic evaluation of paddy harvester and thresher with farm women. International Journal of Science and Research, 3: 1644–1648.

Ghosh D., Singh U.P., Ray K., Das A. (2016): Weed management through herbicide application in direct-seeded rice and yield modeling by artificial neural network. Spanish Journal of Agricultural Research, 14: 1–10.

Ghugare B.D., Adhaoo S.H., Gite L.P., Pandya A.C., Patel S.L. (1991): Ergonomics evaluation of a lever-operated knapsack sprayer. Applied Ergonomics, 22: 241–250.

Government of India (2015): Agricultural Statistics at a Glance 2015. [Dataset]. Available at: https://eands.dacnet.nic.in/PDF/Agricultural_Statistics_At_Glance-2015.pdf.

Karunanithi R., Tajuddin A. (2003): Physiological response of agricultural workers in rice farming operation. Journal of Agricultural Engineering, 40: 33–40.

Kathirvel K., Vidhu K.P., Manian R., Gite L.P., Senthilkumar T. (2004): Test code and procedure for ergonomic evaluation of cono weeder for paddy. Department of Farm Power and Machinery, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Tamil Nadu, India.

Khadatkar A., Potdar R.R., Narwariya B.S., Wakudkar H., Dubey U.C. (2018): An ergonomic evaluation of pedal operated paddy thresher for farm women. Indian Journal of Agricultural Sciences, 88: 280–283.

Nag P.K., Goswami A., Ashtekar A.P., Pradhan C.K. (1988): Ergonomics in sickle operation. Applied Ergonomics, 19: 233–239.

https://doi.org/10.17221/23/2021-RAE

Nag P.K., Nag A. (2004): Drudgery, accidents and injuries in Indian agriculture. Industrial Health, 42: 149–162.

Nag P.K., Sebastian N.C., Mavlankar M.G. (1980): Occupational workload of Indian agricultural workers. Ergonomics, 23: 91–102.

Naughton J., Sevellus G., Balke B. (1963): Physiologic responses of normal and pathologic subjects to a modified work capacity test. Journal of Physical Fitness and Sports Medicine, 31: 201–207.

Ojha P., Kwatra S. (2017): Comparative ergonomic assessment of the male and female farm workers involved in rice cultivation. Journal of Current Microbiology and Applied Sciences, 6: 3439–3446.

Pranav P.K., Biswas M. (2016): Mechanical intervention for reducing dust concentration in traditional rice mills. Industrial Health, 54: 315–323.

Pranav P.K., Patel T. (2016): Impact of ergonomic intervention in manual orange harvester among the workers of hilly region in India. Work: A Journal of Prevention, Assessment, and Rehabilitation, 54: 179–187.

Rajaiah P., Mani I., Kumar A., Lande S.D., Singh A.K., Vergese C. (2016): Development and evaluation of electronically controlled precision seed-metering device for direct-seeded paddy planter. Indian Journal of Agricultural Sciences, 86: 598–604.

Robergs R.A., Landwehr R. (2002): The surprising history of the "Hr_{max}=220-age" equation. Journal of Exercise Physiology Online, 5: 1–10.

Selvan M.M., Annamalai S.J.K., Thavaprakash N., Ananathakrishnan D. (2014): Design and development of three-row improved pull-type rice transplanter for small farmers. Indian Journal of Agricultural Sciences, 84: 1422–1427.

Singh G., Sharma T.R., Bockhop C.W. (1985): Field performance evaluation of a manual rice transplanter. Journal of Agricultural Engineering Research, 32: 259–268.

Singh S. (2009): Physiological workload of women workers in the operation of manual rice transplanters. Gender Technology and Development, 13: 271–284.

Singh S.P., Gite L.P. (2007): Ergonomical assessment of a hand operated paddy winnower by women workers. Journal of Agricultural Engineering, 44: 67–71.

Singh S.P., Gite L.P., Agarwal K.N. (2004): Ergonomical evaluation of manually-operated fertilizer broadcaster with farm women. Journal of Agricultural Engineering, 41: 22–25.

Tang Z., Li Y., Cheng C., Zhong T., Yaoming LI, Cheng C. (2017): Development of multi-functional combine harvester with grain harvesting and straw baling. Spanish Journal of Agricultural Research, 15: 1–10.

Received: March 5, 2021
Accepted: July 30, 2021
Published online: December 17, 2021