



## Ergonomics evaluation of manually operated maize planter by using response surface methodology (RSM)

Sakshi Tomar, Asif Beg\*, Alpna Joshi

School of Agriculture and Environmental Sciences, Shobhit Institute of Engineering and Technology, Deemed-to-be University, Meerut, Uttar Pradesh, India

Corresponding Author: Asif Beg

### Abstract

Maize (*Zea mays L.*) is a significant cereal grown mostly by small and marginal farmers, where manual seeding still predominates due to a lack of machinery. Prolonged manual seeding often causes fatigue, musculoskeletal disorder and decreased field efficiency among workers. The purpose of this study is to evaluate the ergonomics performance of a manually operated maize planter to achieve better field efficiency with the least amount of labour during the seeding/planting operations. Field experiments in normal agricultural situation were conducted to evaluate heart rate, oxygen consumption rate, energy expenditure rate, body part discomfort rating and overall discomfort rate as physiological and postural parameter. Compared to traditional manual seeding, the use of a manually operated maize planter considerably reduced the operator's physical pain and discomfort. Physical activity increased as the oxygen consumption rate increased from 560 ml min<sup>-1</sup> to 730 ml min<sup>-1</sup>, due to the effect of operating depth and age of the operator. The heart rate increased from 109 bpm to 124 bpm as a result of operator age and operating depth. Similarly, energy expenditure rate increased from 17.91 to 24.16 kJ min<sup>-1</sup>, due to the operator age and operating depth. According to a posture analysis, there was improved posture and reduced fatigue in the shoulder and lower back. Planter performance was satisfactory with uniform seed placement and higher efficiency. According to research, the manually operated maize planter is ergonomically safe, reduces labour cost, increases productivity, and provides small and marginal farmers with an affordable maize planting solution.

**Keywords:** Ergonomics, heart rate, oxygen consumption rate, energy expenditure rate, body part discomfort rating and small and marginal farmers

### Introduction

Maize (*Zea mays L.*) is one of the most significant cereal crops in the world, coming in third after wheat and rice. It is used as staple food, animal feed and industrial raw material. Countries such as India are seeing growth in maize cultivation due to its high yield potential, suitability to many agro climatic zones and increased demand from the feed and food processing industries (Dutta *et al.*, 2020) [7]. However, a tremendous proportion of maize is produced by small and marginal farmers with human effort using manual seeding and planting methods (Ajay and Ramireddy, 2024) [1]. Sowing is a crucial operation in crop production that determines plant population, crop establishment and yield. In traditional methods of sowing for maize (manual broadcasting or hand dibbling), achieving the proper plant population is challenging, and the operation is highly labour intensive, resulting in low field efficiency and higher operational time. The operators often end up overstraining themselves and in turn decrease the actual field efficiency of the operation (Singh *et al.*, 2016 and Gupta and Bhardwaj, 2024) [8, 14]. Tractor operated and animal drawn planters are not popular among small and marginal farmers due to their high purchase price and investment, smaller area of land holding, and difficulty of access (Rathod *et al.*, 2024 and Dikkar *et al.*, 2024) [6, 12].

Manually operated maize planters have emerged as a viable option for small and marginal farmers due to their low investment, simple operation and ease of use (Singh *et al.*, 2023) [16]. Often in manually operated agricultural machines, most of the design efforts are directed toward achieving functional performance, while ergonomics consideration

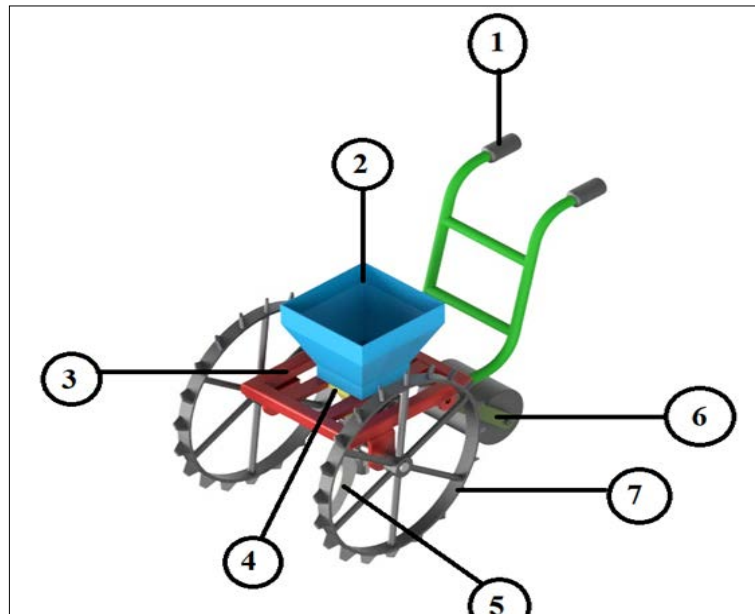
required creating harmony between the human operator and the machine are frequently overlooked. When such tools are not designed with ergonomic principles, their operation demands higher physiological cost and energy expenditure, leading to discomfort in the arms, legs, shoulders, and lower back. Over time, this results in reduced work efficiency and increased risk of musculoskeletal disorders among operators (Ng *et al.*, 2015, Singh *et al.*, 2012 and Suliman and Byers, 2013) [11, 15, 17]. Hence, it becomes essential to conduct ergonomic evaluation of farm tools so that drudgery can be minimized and operational efficiency can be improved according to the physical work capacity of the workers (Kumar and Parihar, 2018, Devi *et al.*, 2019 and Butmee *et al.*, 2024) [3, 5, 10].

Human performance in agricultural operations can be effectively assessed through ergonomic parameters such as heart rate, oxygen consumption rate, energy expenditure rate, along with postural assessment and body part discomfort analysis during machine operation. Measurement of these parameters helps in quantifying the physiological effort involved and identifying necessary design modifications for smoother and safer operation of equipment (Beg and Chauhan, 2023 and Singh *et al.*, 2023, Gupta and Bhardwaj, 2024) [2, 8, 16]. Ergonomics assessment of a manually operated maize planter is especially important since the operator farmer tends to remain in continuous physical contact with the implement during its operation in the field. Previous literature studies in the field of ergonomics assessment of manually operated maize planters and similar machines suggest need for such research in the field (Beg and Chauhan, 2023 and Singh *et al.*, 2023) [16].

Therefore, the ergonomics assessment of a manually operated maize planter under field conditions is the goal of the current work. The parameters studied will help evaluate the performance of the manually operated maize planter in the field as well as that of the human operating it in terms of physiological parameters, and ease or comfort of work. The results obtained could help in enhancing the design of such manually operated machines and also assist small and marginal maize growing farmers in reducing drudgery and increasing productivity in an effort towards sustainable mechanization (Singh and Mehta, 2015 and Kaakkurivaara and Kaakkur, 2021)<sup>[9, 13]</sup>.

**Material and Methodology**

A manually operated single row maize planter is consisting of a ground wheel, handle, frame, furrow opener, seed hopper and seed metering device (Fig.1). The ANOVA was used to determine the individual interaction of all independent parameters at 5% significance level and a 95% confidence level. The optimization of the ergonomics parameters was done using RSM of the design expert software. The optimum values were determined by using the desirability functions and the solution with the desirable value was taken as optimum.



**Fig 1:** Developed planter [1. Handle 2. Hopper 3. Frame 4. Seed plate 5. Furrow opener 6. Rear wheel and 7. Ground wheel]

**Table 1:** Experimental plan of ergonomics evaluation of manually operated maize planter

| S.No | Independent variables | Levels | Details    | Dependent variables   |
|------|-----------------------|--------|------------|---|
| 1    | Subject (age) year    | 4      | 25, 30, 35 | Heart rate (HR), beats min <sup>-1</sup><br>Oxygen consumption rate (OCR), ml min <sup>-1</sup><br>Energy expenditure rate (EER), kJ min <sup>-1</sup><br>Overall discomfort rating (ODR)<br>Body part discomfort rating (BPDR) |
| 2    | Depth of sowing (cm)  | 3      | 4,5,6      |   |

**Heart rate (HR)**

A fingertip pulse oximeter was used to continuously measure the operator’s heart rate (in beats min<sup>-1</sup>) during the sowing process. Recording of heart rate readings was done at intervals of 10 min to accurately represent physiological activity.

**Oxygen consumption rate (OCR)**

Oxygen consumption rate is the amount of oxygen consumed by the body per minute while performing a work operation. Oxygen consumption rate is calculated by using equation 1 (Beg and Chauhan, 2023)<sup>[2]</sup>.

$$OCR = 0.0114 HR - 0.68 \dots (1)$$

Where,

OCR = Oxygen consumption rate, ml min<sup>-1</sup>

HR= Heart rate, beats min<sup>-1</sup>

**Table 2:** Grade of physical work based on HR, OCR

| S. No. | HR, beats min <sup>-1</sup> | OCR, l min <sup>-1</sup> | Grade of work |
|--------|-----------------------------|--------------------------|---------------|
| 1      | <75                         | <0.5                     | Very light    |

|   |         |         |                  |
|---|---------|---------|------------------|
| 2 | 75-100  | 0.5-1.0 | Light            |
| 3 | 100-125 | 1.0-1.5 | Moderately heavy |
| 4 | 125-150 | 1.5-2.0 | Heavy            |
| 5 | 150-175 | 2.0-2.5 | Very heavy       |
| 6 | >175    | >2.5    | Unduly heavy     |

Source: Yadav, et al., 2007<sup>[18]</sup>.

**Energy expenditure rate (EER):** It is the amount of energy the body expends per minute while working and is used to assess load and fatigue. Energy expenditure rate is calculated by using equation 2 (Beg and Chauhan, 2023)<sup>[2]</sup>.

$$EER = \frac{HR-66}{2.4} \dots (2)$$

Where,

Energy expenditure, kJ min<sup>-1</sup>

**Overall discomfort rating (ODR):** Overall discomfort rating (ODR) was used as an indicator of body pain or fatigue induced by the combined effect of posture adopted

during work and increased exertion of the muscles due to different physical work rates of the subjects. The category

Ratio Scale (CR-10) developed by Borg (1982) was used as a measuring scale for the calculation of ODR (Fig. 2).

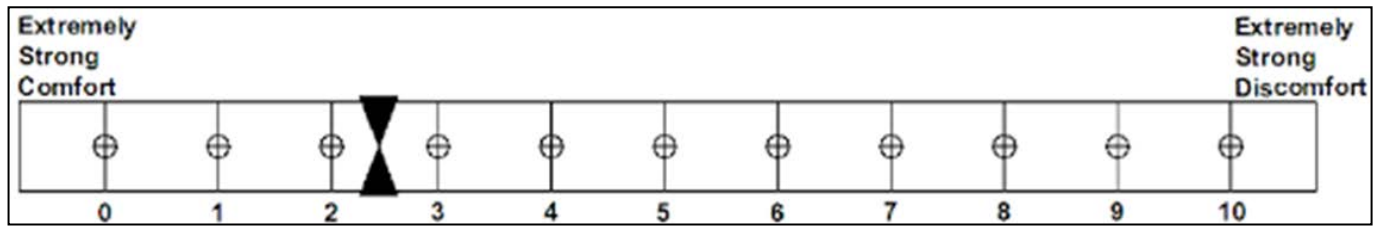


Fig 2: Overall discomfort rating scale

**Body part discomfort rating (BPDR):** The body part discomfort rating (BPDR), which is the measure of discomfort, may limit the duration of work based on the static load applied to the body part. The BPDR is computed

using the method proposed by Corlett and Bishop (1976)<sup>[4]</sup> (Fig. 3). The level of pain and exhaustion felt by the subjects is recorded using the category ratio scale CR-10 after dividing the body into 27 sections.

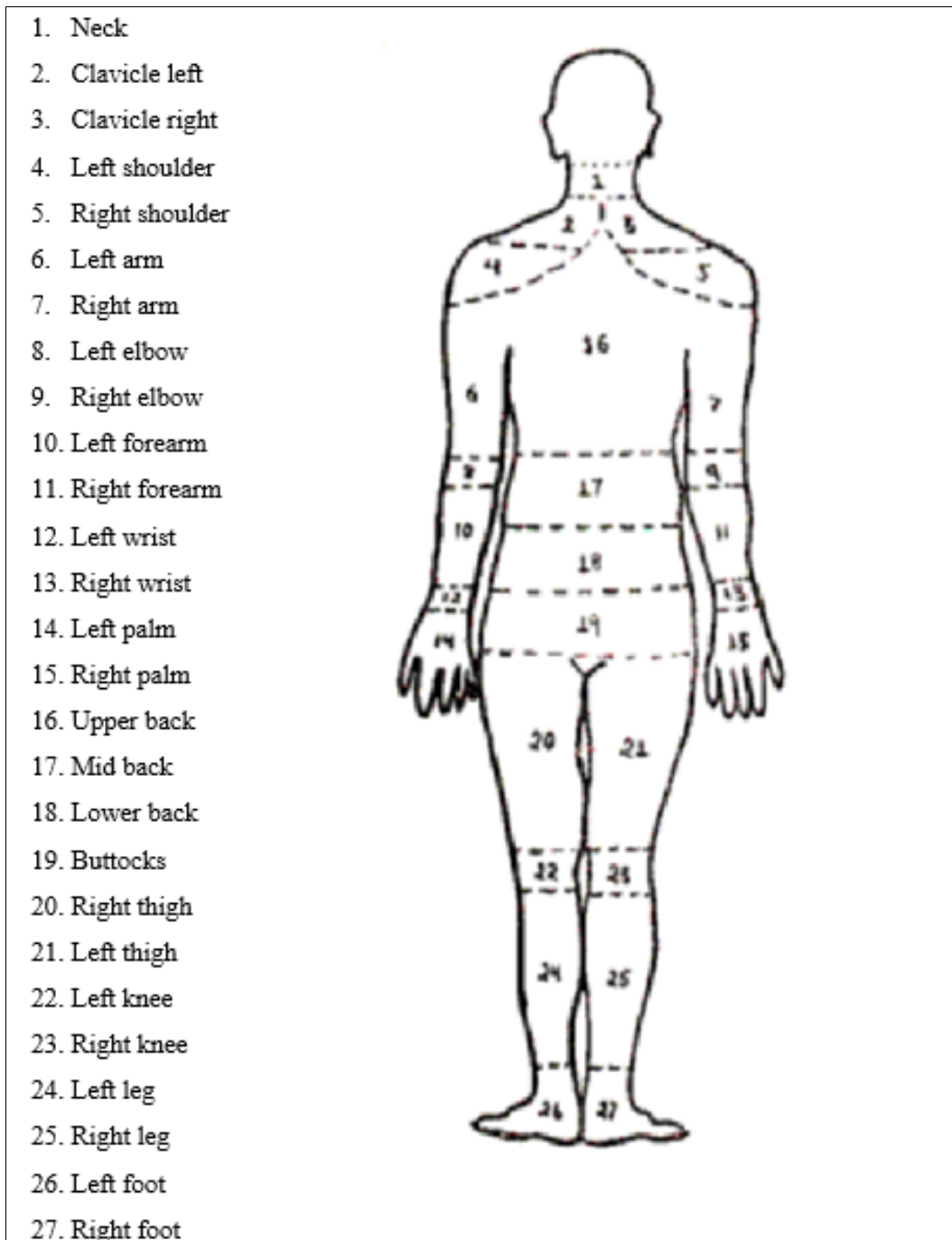


Fig 3. Regions for evaluating body part discomfort

**Result and Discussion**

To design the experiment and analyze the data, ANOVA and Design-Expert software were used to assess the impact of the treatments referred to as control or fixed factors [subject age (A) and depth of sowing (B)] on key responses, including heart rate, oxygen consumption rate, energy expenditure rate, overall discomforting rating and bodypart discomfort rating respectively.

**Analysis of Variance**

Analysis of variance (ANOVA) was employed to assess the individual interactions among all control factors in the experiment. In this study, ANOVA evaluated the impact of independent variables on dependent variables at a 5% significance level and 95% confidence interval, with results summarized in Tables 4 to 8. According to table 4, revealed that heart rate was significantly affected by the operator's age and depth at 5% significant level. Thus, age of the

operator was the most significantly affecting factor for heart rate. Table 5 shows that the operator's age and depth significantly influenced the oxygen consumption rate at the 5% significance level. Among these, the operator's age emerged as the primary factor affecting oxygen consumption rate. Table 6 indicates that the energy consumption rate was significantly influenced by the operator's age and operating depth at the 5% significance level. Among these factors, the operator's age exerted the most substantial effect on the energy consumption rate. Table 7 indicates that the overall discomfort rating was significantly influenced by the operator's age and operating depth at the 5% significance level. Among these factors, the operator's age emerged as the most significant determinant of the overall discomfort rating. Table 8 revealed that body part discomfort rating was significantly affected by the operator's age and depth at 5% significant level. Thus, age of the operator was the most significantly affecting factor body part discomfort rating.

**Table 3:** Optimization parameters for ergonomics

| S.N. | Factors  |        | Mean Response          |                                  |                                  |                           |                             |
|------|----------|--------|------------------------|----------------------------------|----------------------------------|---------------------------|-----------------------------|
|      | A (year) | B (cm) | Herat rate (Beats/min) | Oxygen Consumption Rate (ml/min) | Energy Expenditure Rate (kJ/min) | Overall Discomfort Rating | Body Part Discomfort Rating |
| 1    | 35       | 5      | 119                    | 670                              | 22.08                            | 3                         | 36                          |
| 2    | 30       | 5      | 115                    | 630                              | 20.41                            | 3                         | 38                          |
| 3    | 35       | 6      | 124                    | 730                              | 24.16                            | 4                         | 42                          |
| 4    | 30       | 5      | 115                    | 630                              | 20.41                            | 3                         | 38                          |
| 5    | 25       | 4      | 109                    | 560                              | 17.91                            | 2                         | 30                          |
| 6    | 25       | 5      | 114                    | 610                              | 20                               | 2                         | 34                          |
| 7    | 30       | 4      | 111                    | 580                              | 18.75                            | 2                         | 33                          |
| 8    | 30       | 5      | 115                    | 630                              | 20.41                            | 3                         | 38                          |
| 9    | 35       | 4      | 115                    | 630                              | 20.41                            | 2                         | 34                          |
| 10   | 30       | 6      | 121                    | 690                              | 22.91                            | 4                         | 42                          |
| 11   | 25       | 6      | 118                    | 660                              | 21.66                            | 3                         | 40                          |
| 12   | 30       | 5      | 115                    | 630                              | 20.41                            | 3                         | 38                          |
| 13   | 30       | 5      | 115                    | 630                              | 20.41                            | 3                         | 38                          |

**Table 4:** ANOVA for heart rate

| Sources             | Sum of Squares | df | Mean Square | F-value | P-value |
|---------------------|----------------|----|-------------|---------|---------|
| Age of the operator | 48.17          | 1  | 48.17       | 248.59  | <0.0001 |
| Depth of sowing     | 130.67         | 1  | 130.67      | 674.37  | <0.0001 |
| Residual error      | 1.36           | 7  | 0.1938      |         |         |

**Note:** Significant at 5% level of significance, P<0.05 Determine significance of factor at 95% of confidence level

**Table 5:** ANOVA for oxygen consumption rate

| Sources             | Sum of Squares | df | Mean Square | F-value | P-value |
|---------------------|----------------|----|-------------|---------|---------|
| Age of the operator | 6666.67        | 1  | 6666.67     | 700.00  | <0.0001 |
| Depth of sowing     | 16016.67       | 1  | 16016.67    | 1681.75 | <0.0001 |
| Residual error      | 66.67          | 7  | 9.52        |         |         |

**Table 6:** ANOVA for energy expenditure rate

| Sources             | Sum of Squares | df | Mean Square | F-value | P-value |
|---------------------|----------------|----|-------------|---------|---------|
| Age of the operator | 8.35           | 1  | 8.35        | 244.28  | <0.0001 |
| Depth of sowing     | 22.66          | 1  | 22.66       | 662.55  | <0.0001 |
| Residual error      | 0.2394         | 7  | 0.0342      |         |         |

**Table 7:** ANOVA for overall discomfort rating

| Sources             | Sum of Squares | df | Mean Square | F-value | P-value |
|---------------------|----------------|----|-------------|---------|---------|
| Age of the operator | 0.6667         | 1  | 0.6667      | 22.25   | <0.0022 |
| Depth of sowing     | 4.17           | 1  | 4.17        | 139.04  | <0.0001 |
| Residual error      | 0.2098         | 7  | 0.0300      |         |         |

**Table 8:** ANOVA for body part discomfort rating

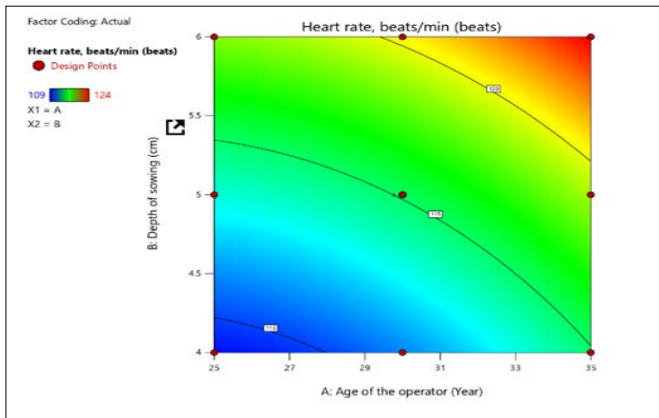
| Sources             | Sum of Squares | df | Mean Square | F-value | P-value |
|---------------------|----------------|----|-------------|---------|---------|
| Age of the operator | 10.67          | 1  | 10.67       | 24.15   | <0.0017 |
| Depth of sowing     | 121.50         | 1  | 121.50      | 275.07  | <0.0001 |
| Residual error      | 3.09           | 7  | 0.4417      |         |         |

**Analysis of the Operating Parameters for Heart Rate (HR)**

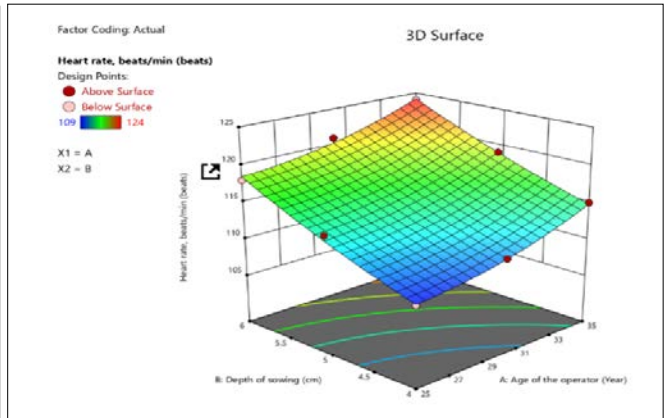
The relationship between the age of the operator and the sowing depth with respect to the heart rate, (beats min<sup>-1</sup>) Fig a .The graph clearly shows that operator heart rate increases as age and sowing depth rise. At lower age of operator, 25 year and lower sowing depths of 4 cm, the heart rate will stay lower, at about 109 beats min<sup>-1</sup>, which indicates lower physiological efforts from the part of the operator. As for the higher heart rates about 124 beats min<sup>-1</sup> when sowing depth of 6 cm and operator age reach 35 years, the curve shape shows the relationship between the two factors (age and depth) is not purely linear.

Impact of the two factors on age of the operator (A) and depth of sowing (B) is

shown in 3D surface Fig (b). In the graph, there is a clearly indicated positive trend of heart rate as both age and depth of sowing increase, with the vertical Z-axis showing the level of heart rate. The surface shown in the graph starts off from blue color which indicates low levels of heart rates due to low sowing depths and low age. Orange-yellow color shows increased heart rate associated with high sowing depths and old age. From the experimental data, the dots are colored either red or pink, giving clues if the observations are above or below the modelled surface. It can be observed that for the operator whose age is 25 years with sowing depth of 4 cm, the heart rate reaches its lowest point of 109 beats min<sup>-1</sup>. On the other hand, the heart rate goes up to 124 beats min<sup>-1</sup> for a person aged 35 years sowing at depth of 6 cm.



(a) Contour plots for Age of the operator and Depth of sowing



(b) Response surface for Age of the operator and Depth of sowing

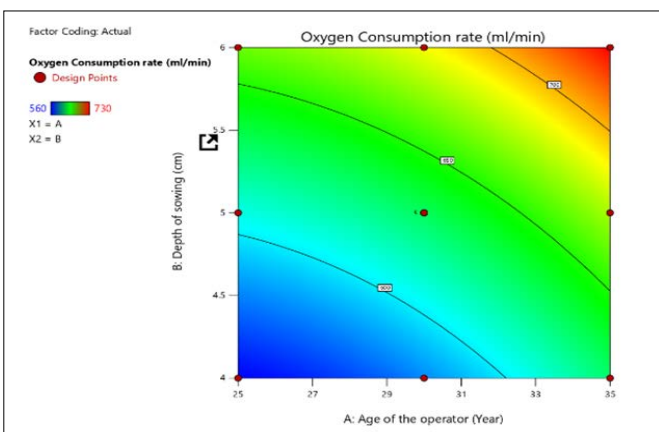
**Fig 4:** Effect of several factors on heart rate

**Analysis of the operating parameters for oxygen consumption rate (OCR)**

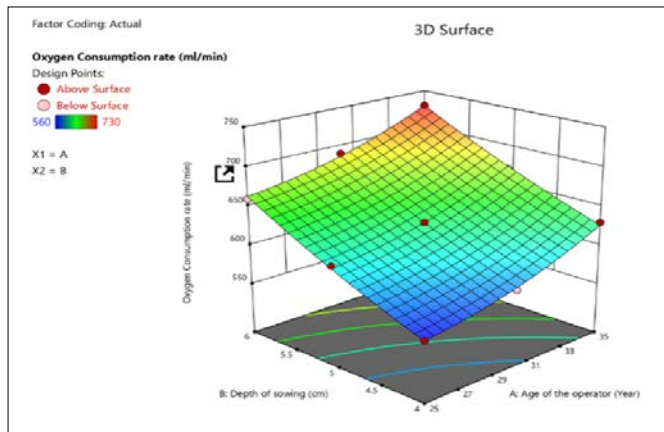
As illustrated in this graph Fig. a, the oxygen consumption levels slowly increase in the top right quadrant where the values of both variables are maximum at 730 ml min<sup>-1</sup>, while they are minimum at the bottom left quadrant, when both variables have smaller values of 560 ml min<sup>-1</sup>. The effect of both variables age, and sowing depth, on oxygen consumption can be regarded as interactive and not purely additive, since the curvature of contour lines indicates the presence of a nonlinear relationship. Sowing depth has a more pronounced effect on oxygen consumption compared to age, especially for 35 years-old operators. The locations

where measurements have been conducted are indicated by red dots.

The effect of the age of the operator (25 to 35 years) and depth of sowing (4 to 6 cm) on OCR (ml min<sup>-1</sup>) can be seen from the following figure (b). The X-axis scale ranges from 25 to 35 years of age of the operator, while the range of the Y-axis varies from 4 to 6 cm depth of sowing. In the graphical representation of the data, the trend of OCR value from its minimum to maximum value can be seen from blue color representing the lowest value of 25 years of age of the operator and 4 cm depth (560 ml min<sup>-1</sup>) to red/orange representing the highest value of 35 years of age of the operator and 6 cm depth (730 ml min<sup>-1</sup>).



(a) Contour plots for Age of the operator and Depth of sowing



(b) Response surface for age of the operator and depth of sowing

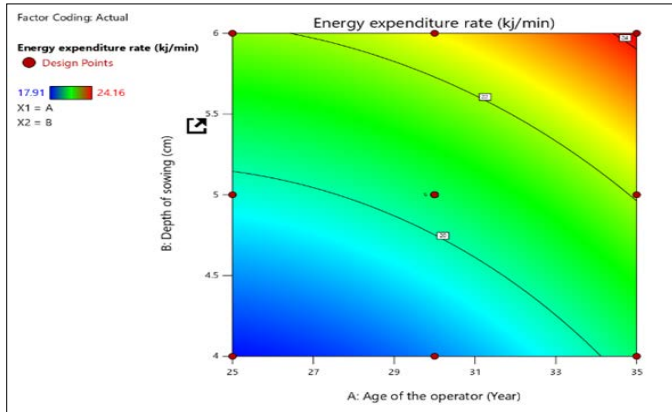
**Fig 5:** Effect of several factors on oxygen consumption rate

**Analysis of the operating parameters for energy expenditure rate (EER)**

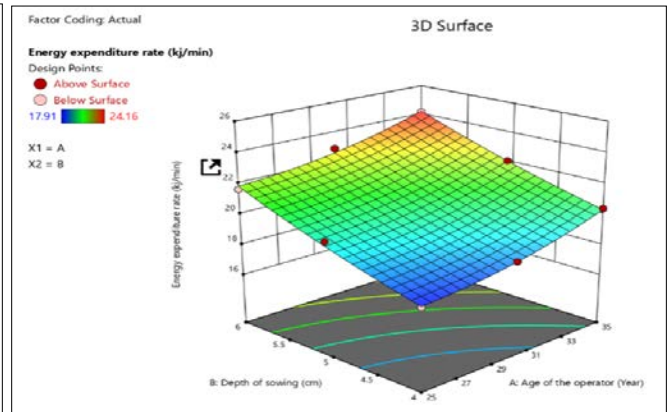
Figure 6(a) graphically illustrates the correlation between energy consumption rate ( $\text{kJ min}^{-1}$ ), operator age (years) on the X-axis, and seeding depth (cm) on the Y-axis. Color gradients on the surface represent energy use levels, with warm tones (yellow to red) indicating the peak at  $24.16 \text{ kJ min}^{-1}$  and cool tones (blue to green) showing the minimum at  $17.91 \text{ kJ min}^{-1}$ . The lower left region, corresponding to younger operators and shallower depths, exhibits the lowest energy consumption. As age and depth increase, colors shift from blue-green to yellow-red, reflecting rising energy demands. Contour lines (isolines) mark combinations of age and depth yielding equivalent energy rates; their curved shapes highlight nonlinear

interactions between the variables.

The correlation of age of the operator and sowing depth, relation to the energy expenditure rate,  $\text{kJ min}^{-1}$ , Fig. (b). Depending on age and depth, energy expenditure rate varies in a range  $17.91 \text{ kJ min}^{-1}$  to  $24.16 \text{ kJ min}^{-1}$ . From the bottom of this model, it is seen that EER reaches its minimum point at  $17.91 \text{ kJ min}^{-1}$ , at minimum depth of 4 cm is achieved at an age of 25 years, denoted with the help of the dark blue colour of the surface. With the increase of the two variables, the energy expenditure is increased too. Especially, when 6 cm of depth is achieved by rising the operator's age up to 35 years, EER will reach its maximum point of  $24.16 \text{ kJ min}^{-1}$ , denoted with the help of the red-orange colour of the surface. Red and pink spots are experimental data points relative to the model.



(a) Contour plots for age of the operator and depth of sowing



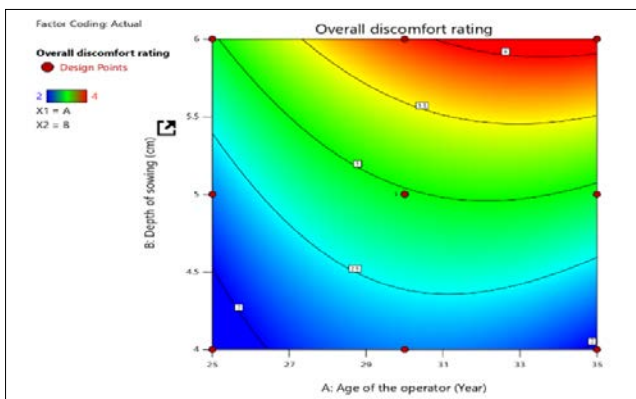
(b) Response surface for age of the operator and depth of sowing

**Fig 6:** Effect of several factors on energy expenditure rate

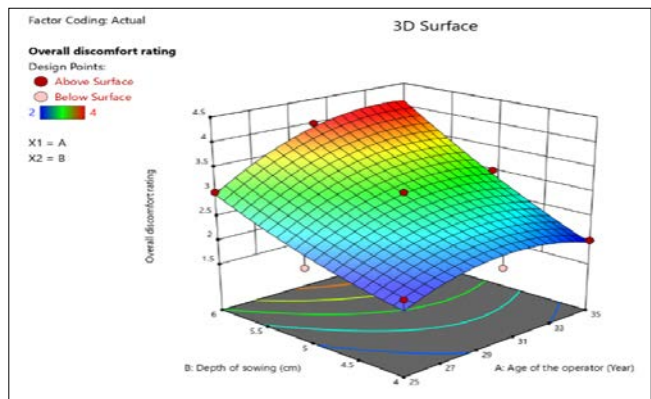
**Analysis of the operating parameters for overall discomfort rating (ODR)**

The impact of the age of the operator (A) and depth of sowing (B) on overall discomfort rating as seen in Fig (a). In the bottom-left corner of the graph, with low depths of sowing and age, less pain can be seen. More pain is shown when there is age or depth increase, starting from green to yellow then red. The curve contour represents a nonlinear correlation between the two variables and shows all the points of equal pain from different depths and age combinations. There is more pain observed in the top right corner of the graph, particularly when there is higher age and deeper depths. It appears like there is a combination of the two variables, with the effects of pain becoming more pronounced when there is increased depth of sowing.

The relationship between the level of discomfort (vertical axis) and variable a (operator age, years) and B (depth of sowing, cm) can be seen from this Fig (b), which shows in three dimensions. It is clear how discomfort is related to different pairs of age and depth from the way that the surface changes color from blue, indicating low levels of discomfort, to red, showing high levels of discomfort. It can be noted that as the operator ages, along with a greater depth of sowing, there is an increase in discomfort, the highest being recorded for high values of the two factors. On the contrary, the smallest level of discomfort occurs at lower depths and ages of the operators. This can be explained by looking at the projected contour lines on the bottom, which indicate a constant increase in pain for both variables.



(a) Contour plots for age of the operator and depth of sowing



(b) Response surface for age of the operator and depth of sowing

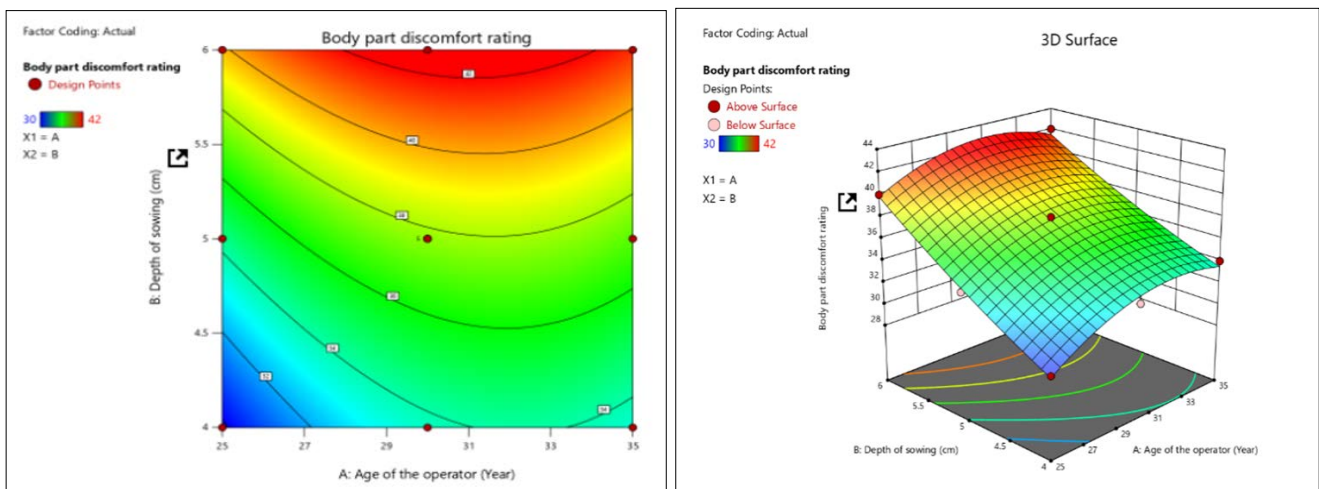
**Fig 7:** Effect of several factors on overall discomfort rating

### Analysis of the operating parameters for body part discomfort rating (BPDR)

The relationship between age of operator and depth of sowing on the body part discomfort rating has been represented graphically as in figure 8(a). It is quite clear from the color scale that ranges from blue to red in proportion to the increasing level of discomfort that an increase in age or depth of sowing causes an increase in discomfort. At bottom left corner, where age of operators was 25 years with low depth of sowing, there was minimum pain of 30. At top right corner, where age of operators was 35 year with maximum depth of sowing, there was maximum pain of 42. As the depth or age increases, the pain also increases from green to yellow.

The pain rating is shown in Fig 8(b) by the vertical axis and the surface color changes from blue (low discomfort) to red (high discomfort). As age and sowing depth rise, the plot

clearly demonstrates a rising tendency in discomfort. Higher depths paired with 35 year operators are associated with the highest discomfort values 42, while the lowest discomfort values are found in the area where both age and depth are limited 30. A nonlinear relationship and interaction between the two variables are indicated by the smoothly curved surface, which means that the impact of one element relies on the level of the other. This pattern is further supported by the contour projection at the base, which displays steady rises in pain along both axes. Plotting the experimental design points on the surface, some of which are slightly above or below it, shows that the model predictions and actual observations coincide rather well. Overall, the figure shows that greater body part discomfort is a result of both increasing sowing depth and growing operator age, with depth once more proving to have a significant impact.



(a) Contour plots for age of the operator and depth of sowing

(b) Response surface for age of the operator and depth of sowing

**Fig 8:** Effect of several factors on Body Part Discomfort Rating

### Conclusion

Based on the study undertaken, following conclusions can be drawn.

- Heart rate reached a minimum of 109 beats  $\text{min}^{-1}$  at a sowing depth of 4 cm and a maximum of 124 beats  $\text{min}^{-1}$  at 6 cm.
- Oxygen consumption rate (OCR), with the maximum value of 730  $\text{ml min}^{-1}$  recorded at 6 cm depth of sowing and 35 years of age of the operator, and the minimum of 560  $\text{ml min}^{-1}$  at 4 cm depth and 25 years of age.
- Energy expenditure rate increased with both operator age and sowing depth, ranging from 17.91  $\text{kJ min}^{-1}$  to 24.16  $\text{kJ min}^{-1}$ .
- Overall discomforting rating (ODR) exhibited a direct positive effect from both age of the operator and depth of sowing.
- The body posture discomfort rating (BPDR) showed a maximum of 42 at 35 years of age and 6 cm depth, and a minimum of 30 at 25 years of age and 4 cm depth.
- The analysis of variance (ANOVA) revealed that the age of the operator and the depth of sowing were significant parameters.

### Acknowledgement

Authors acknowledge Shobhit Institute of Engineering and Technology (Deemed-to-be University) Meerut, for using its facility to conduct the study.

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