Mathematical model for design of farm equipment suitable to relevant workers

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Abstract: During last three decades, many research organizations in the country are working on assessment, refinement and development of gender friendly farm equipment. Based on various study conducted on gender perspective, a need is felt to work on modeling in a specific method to create a mathematical process in solving problems, for design and development of farm equipment for relevant workers in the field, particularly weeder. The mathematical model developed clearly indicates influencing factors such assoil condition, equipment, tool geometry and human factors for achieving indented output with mechanical weeders. Dynamic instability of the equipment is responsible for requirement of excess push force. The developed model will be helpful in designing the weeder that avoid slip angle to overcome extra force required to push the equipment. The models developed are successfully validated with measured values which confirms its acceptability in getting force data and design of weeder as per anthropometric and strength data. The researcher can easily adopt the developed model for designing new weeder or refining/modifying the existing to reduce load on operators due to machine working.

Keywords: weeder, gender-friendly, mathematical model, design, push force, pull force

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1 Introduction

After green revolution in India, production of crops has been enhanced considerably (2.4 times from year 1971 to year 2016) (GOI, 2016), but for further increment with reduced cultivated area, there is need to complete the unit farm operations with less time and drudgery free working environment with high precision of work. Unit farm operations are carried out in different types of crop management practices where human beings are involved either as power source or controller or guide for most of the traditional as well improved farm equipment/ machines. The involvement of women in majority of farm operations is passive type (in terms of farm mechanization) such as in field preparations (clod breaking, taking out weeds etc.), assistance in sowing (dropping seeds or carrying seeds), weeding and interculture, harvesting, assistance in threshing, winnowing, cleaning-grading, carrying produce as well as grain to home etc. Various types of farm tools and equipment have been developed for majority of the farm operations. However, these are not always suitable for both the gender, due to their different ergonomical characteristics (Singh et al., 2006) therefore, equipment should be gender neutral or for relevant workers. Manually driven implements are basically pull or push mode type even sometimes combination of both. The pull and push operations affect human health causing lower back injury (Hoozemans et al., 1998) and also increasing risk of shoulder injury (Van der Beeket al., 1993). Push and pull operations are also associated with low back injuries or claimed (9%-20%) as reported by NIOSH (1981) and Hoozemans et al. (1998). Farm operations performed by human-beings are generally dynamic in nature while structure of farm tools and equipment are mostly static/isometric, which has effect on human body as well as the operational productivity. The main components that are responsible for body parts injury, are

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magnitude and force direction (De Looze et al., 2000). Lack of seriousness among workers as well as bystander, while accident happened, even often they laugh and makes joke and does not regard it seriously (Manning, 2007). To overcome the above points, ergo-mechanical approach for designing the equipment suitable for men and women farm workers is tried by some of designers/investigators. The ergonomics is only science that mainly focuses human-beings as in center point to design tools/equipment/machine, based on environment, posture, safety, output etc. Body posture and friction at the shoe/floor interface are identified as the most important factors that determine push and pull exertion capability (Martin and Chan, 1972; Ayoub and McDaniel, 1974; Kroemer, 1974). Perfect body posture has capability to produce optimum force for push and pull operations (Daams, 1993) and also minimize the accident. Based on study on the body posture, different researchers recommend methods of designing handle height (Martin and Chaffin, 1972; Giteand Yadav, 1989; Singh et al., 2016), handle width, and shoulder position (Ayoub and McDaniel's, 1974). The whole process of making gender-friendly farm tools and equipment is lengthy. Work on algorithms or modeling has been done on repair and maintenance costs of tractors (Bowers and Hun, 1970; Beppler and Hummedia, 1985; Almassi and Yeganeh, 2002; Rashid and Ranjbar, 2010; Adekoya and Otono, 1990; Gautam and Shrivastava, 2017), but not on farm equipment, particularly weeder. Therefore, an attempt was made to create a mathematical process in solving problems using ergonomic data, which may be conceptual comprising of a set of steps that a designer takes in consideration to reach a specific goal.

2 Materials and methods

Human-machine interface is a key factor in all these farm operations such as seeding, weeding, spraying, harvesting, cleaning, winnowing, grading etc. Out of these, weeding is a most active operation in fields during Kharif and Rabi seasons. Mechanical weeders have been developed for weeding purpose which is carried out by using either in push-pull mode or pull mode (Pandey et al., 1997; Singh et al., 2016). Twin-wheel hoe and cono-weeder are popular weeding equipment- which are operated by a farm worker in push-pull modes or only pull or push mode (Singh et al., 2007; Sridhar, 2013). Under these modes of operation, push (from rear side of weeder) or pull force (from front side of weeder with rope or other arrangement) is the main component that required for removing weeds. Manually operated weeders (single wheel hoe, cono-weeder and four-wheel weeder) are taken into consideration for development of mathematical model to solve the designing and operational complicacy. For development of the systematic modeling technique, the parameters such as force analysis, work done by worker and machine parameters were considered.

2.1 Force analysis

In case of operation with push-pull type weeders, push force is utilized for weeding whereas pull force is required for repositioning the equipment to generate acceleration in next step of push operation and thus it completes one cycle of operation. Push and pull operations are performed by expansion and contraction of human muscles. Application of push force is an active stage of weeding operation in which the force is applied for removing of weeds. Next part of acycle is termed as pull operation which is a kind of idle operation in terms of weed removing process. Energy utilized under pulling operation is basically utilized for repositioning the equipment at equilibrium position. Thus, the total force requirements for push-pull operation under such boundary condition is function of width of blade (W), depth of weeding (d), friction (f_r) and cutting force (R) in pushing the equipment whereas rolling resistance (R_r) and weight of weeder (W_w) act during pulling. Therefore, mathematical representation of push (F_{push}) and pull (F_{pull}) force are as below.

$F_{push}=f(W\ d\ R\ f_r)$

$F_{pull}=f(f_r)$

Mathematical explanation for total push force requirement is expressed as summation of cutting force and frictional resistance force in following equation. Soil accumulation during weeding on top of weeding blade is assumed negligible.

$$\sum F_{push}=\sum(RWd)+(f_r) \qquad (1)$$

Similarly, total pulling force requirements is equal to total frictional force.

$$\sum F_{pull}=f_r \quad (2)$$

Total force requirements during a cycle of push-pull mode of operationis expressed as

$$\sum F=\sum F_{push}=\sum F_{pull} \quad (3)$$

Based on Equations 1 to 3, a matrix has been prepared for assessing the force requirement with both type of farm workers (men, F_M and women, F_F).

$$\begin{Bmatrix} F_M \\ F_F \end{Bmatrix} = \{R\}\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\{W\}\begin{Bmatrix} d_1 \\ d_2 \end{Bmatrix} + \{f\}$$

where, R: rolling resistance, N·m^{-2}; W: working width of weeding blade, m d_1: operational depth with men workers, m; d_2: operational depth with women workers, m; f_r: frictional force, N.

After solving the above equation for men and women workers separately, a common force equation is derived below.

$$\{F\}=\{\rho\}\{W\}\{d\}\{f\}$$

2.2 Work done by the worker

Following boundary condition is expressed for work-done (e) analysis in weeding operation by considering displacement (X) and velocity (V) of farm worker with time series (0 to t).

$$X(0)=0 \quad V(0)=0 \quad e(0)=0$$

$$X(t)=L \quad V(t)=V \quad e(t)=E$$

Force acting on an object is dependent on position and time. However in many cases it is assumed that small displacement (dx), force acting are constant. But in practical it is not true, therefore for integration of total force is attempted to find the total work done (E) in a complete cycle of pull-push operation.

$$e_{push} = \int_{t_0}^{t_1} F_{push} V_{push} dt \quad (4)$$

$$e_{pull} = \int_{t_1}^{t_0} F_{pull} V_{pull} dt \quad (5)$$

By solving above equations, total work-done (E) is

$$E = \int_{x_0}^{x_1} F_{push} dx + \int_{x_1}^{x_0} F_{pull} dx \quad (6)$$

Based on Equation (6), a matrix has been prepared for determining the work-done by both type of farm workers (men, E_M and women, E_F).

$$\begin{bmatrix} E_M \\ E_F \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}\begin{bmatrix} X_{push} \\ X_{pull} \end{bmatrix}\begin{bmatrix} F_{push} \\ F_{pull} \end{bmatrix}$$

$$\{E\}=\{\tau\}\{F\}$$

This equation enables designer to understand the work-done by male and female operators separately which will help designer in selection of appropriate data applicable to men or women farmers.

2.3 Stability of equipment

In case of manual operated weeder, stability of equipment is necessary to reduce the idle muscle load on workers for smooth and efficient operations. Since the operation is being done by human beings, the stability is dynamic in nature. Thus, design of weeder, operators and operational parameters are considered as main design parameters for analyzing the stability of equipment which is represented in Figure 1.

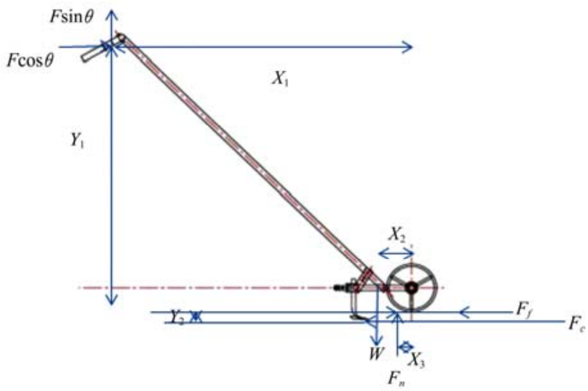

Figure 1 Free-body diagram of different forces on manual weeder

During push-pull mode of weeding operation, elbow extension and flexion are in function, therefore, push and pull force in X-direction is represented below.

$$\sum F_{x\ extension}=F_{push}-F_{cutting}-F_f \quad (7)$$

$$\sum F_{x\ flexion} = F_{pull} - F_{rf} \quad (8)$$

Similarly in Y-direction, the resultant force (F_y) is represented in Equation (9) considering soil reaction force (F_n) and weight of equipment (w).

$$\sum F_y = F_n - w \quad (9)$$

In Z-direction, lateral component (F_z) is expected due to undulation and side thrust which is represented in Equation (10) considering soil lateral forces (F_l) in positive direction and opposite to external force (F_e).

$$\sum F_z = F_l - F_e \quad (10)$$

Therefore, moments are expressed in Equation (11) - (14) by considering push force, frictional force (F_f) and cutting force (F_c) with respective distance Y_1, Y_2 and Y_3, respectively. In Z-direction, lateral force (F_l) and external force (F_e) are considered.

$$\sum M_x = F\cos\theta Y_1 - F_c Y_2 \quad (11)$$

$$\sum M_x = F\cos\theta Y_1 \quad (12)$$

$$\sum M_y = wX_2 - F_n X_3 - F\sin\theta X_1 \quad (13)$$

$$\sum M_z = F_l Y_2 - F\cos\theta Y_1 \quad (14)$$

Force is applied at the point of handle for allowing it to move forward. The momentum that develops under such condition must be in equilibrium to avoid the overturning or twisting. In 3-dimensional frame, overall force is resolved into three different planes.

$$F = F_x i + F_y j + F_z k$$

$$F = F'F \quad (15)$$

where, F: resultant force, N; $F'F$: scalar component of F acting in x, y & z plane, N; λ: unit vector along the line of action F.

2.4 Machine parameters

Machine size is determined on the basis of operational demand, machine stability and power source. Row spacing is a major factor for designing of mechanical weeders. Stability factor and weight of the machine are considered for determining the machine length (l) and width (W) of manual operated weeder.

$$Area(A) = l \times W$$

$$A = f(l\ W) \quad (16)$$

where, A: area, m^2, l: length of machine, m; W: width of machine, m.

The weight of weeder should not exceed 30% of 5th percentile body weight of farm women which is about 10 kg (Singh et al., 2016). The maximum length of weeder may be decided based on wheel arrangement and number of wheels. But it is observed that maximum length may be restricted up to 600 mm (Singh et al., 2016). The width of weeder is normally 150 mm for manually operated weeder which can be kept up to 250 mm with adjustment of weeding depth. V-shape sweep is preferred as the tool geometry of the cutting blades is based on soil-tool-plant interactions (Bernacki et al., 1985). The maximum push force with both hands by a man and woman worker in standing posture is 498 and 302 N, respectively (Gite et al., 2009) but for better muscular efficiency, the dynamic effort of a repetitive nature should not exceed 30% of the maximum push force (Grandjean, 1988). Relationship between mechanics of weeding action and soil resistance could be expressed as below.

$$F\cos\phi_p = w\ d_w R_s \quad (17)$$

where, F = sustainable push force (i.e. 30% of 498 N or 302 N=149 N or 91 N); ϕ_p = Angle of operation for weeder by a worker (comfortable operational angle 30°-45°, Gite and Yadav, 1989); w = Weeding width, mm; d_w = Weeding depth, mm (15-20 mm for this weeder); R_s = Specific soil resistance (value of 0.02 N mm^{-2} for heavy soil up to 150 mm depth (Bernacki et al., 1985).

After analyzing, weeding width comes in range of 351-430 mm and 263-322 mm at operation angle 45° & 30° by male worker for weeding depth of 15 and 20 mm, respectively. Similarly, with female worker, corresponding values for weeding width are 215-263 mm and 161-197 mm. Effect of handhold height on body posture is pronounced because that a person is able to generate force which directly related to posture. Research shows at different elbow angle, the force required in pull-push mode is different at varying handle height. The optimum handle height (H) is needed to design for utilizing maximal amount of body force for intended function. The designing factor of handle height is elbow height and elbow angle. The optimum handle height is expressed based on these two parameters as shown below in Figure 2.

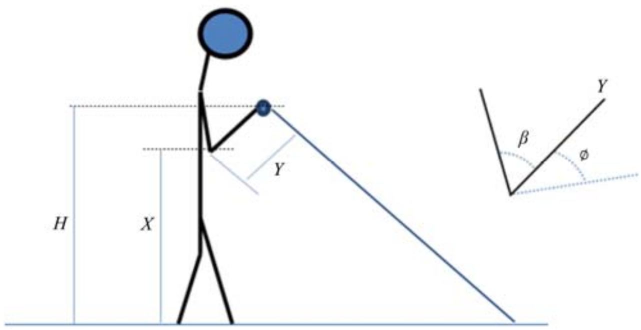

Figure 2 Schematic diagram of force exerted by human beings

From this figure, the flexion and extension of hand is represented mathematically and can be expressed as below.

$$H = X + YCos\beta \quad (18)$$

where, H: height of handle from ground, m; X: elbow height from ground, m; Y: elbow grip length, m; β: angle between upper and lower arms, m.

$$\left\{\begin{bmatrix} H_5 \\ H_{95} \end{bmatrix}\right\} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} x_5 \\ x_{95} \end{bmatrix} + \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} y_5 \\ y_{95} \end{bmatrix}\{Cos\beta\}$$

The body posture of human being during operation of equipment in the field is of dynamic nature which varies in its pull and push modes. Thus, this dynamicity requires flexible handle height for efficient operation of equipment.

Handle height flexibility is depending parameter of elbow rotational angle (β). The acceleration force required to operate the equipment is generated in between the angle $Ø_0$ to $Ø_{max}$ ($Ø_0$=90–β) by the application of pushing force. Flexible angle and length of elbow also decide the operating length during its operation by a worker. Due to physiological diversification, different body posture could be found during push-pull modes of operation.

During push pull operation, maximum force that a worker can exerts is dependent on the hand position. Worker can exert optimum amount of force while the elbow joint are in co-planer to shoulder. Therefore, the optimum handle width (HW) is expressed as below.

HW= 5th and 95th percentiles bideltoid width of workers

Again, the length covered per cycle of push operation is function of body parameters and working posture. Under 5th and 95thpercentiles concept of body posture human elbow length varies, that has effect on working length covered per cycle. Therefore, virtual arc (S) developed by elbow Y is defined as

$$S=Ø\times Y \tag{19}$$

where, S: virtual arc, m; Y: elbow grip length, m; Ø: angle between elbow grip length to horizaontal plane, °.

The above formula is applicable in case of static condition while operation is dynamic. So, length covered (L) is a factor of movement of shoulder during operation (Figure 3) which is termed as correction factor 'C'. Linear distance covered by the equipment is function of arc length. Normally movement of shoulder is up to 10° therefore cosine component that acts on the operational length can be defined as below.

$$S=\int_{\varnothing_1}^{\varnothing_2}\varnothing\times Y$$

$$L=C\times S \tag{20}$$

where, C: correction factor; S: virtual arc length, m.

The mathematical model developed for manual weeder was tested with the data obtained from same field. The angle was measured with angle finder. The force requirement in operation of single wheel hoe, swinging type cono-weeder and four-wheel weeder was measured using load cell with suitable fixtures. Total force requirements (push+pull) were calculated as per data given in Table 1 using Equation (1)-(3). The push-pull force cycle in operation of swinging type cono-weeder, single wheel hoe and four-wheel weeder in field was presented in Figure 4-6. The work done was calculated by measuring push force during each stroke of selected weeders. Three readings were taken for each stroke to get average value and readings were taken for 10-12 strokes, which was presented in Figure 7.

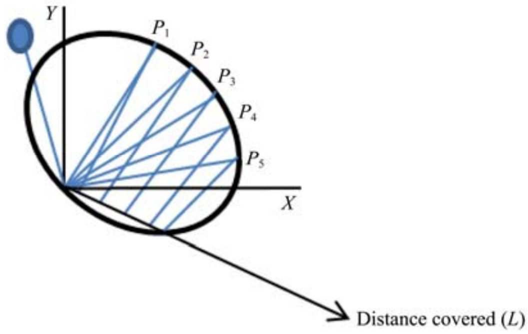

Figure 3 Shoulder movement during operation for distance covered

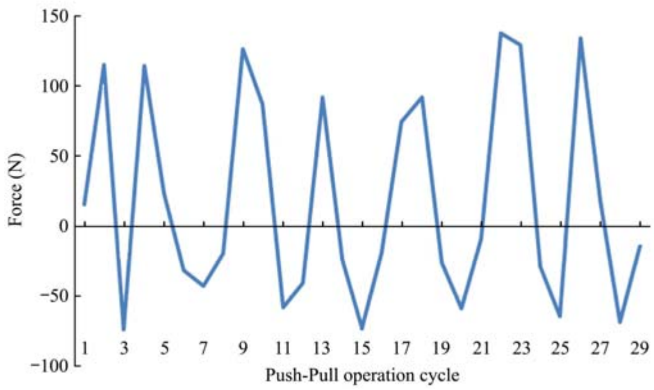

Figure 4 Push (above reference line from zero N) -pull force (below reference line from zero N) cycle in operation of swinging type cono-weeder

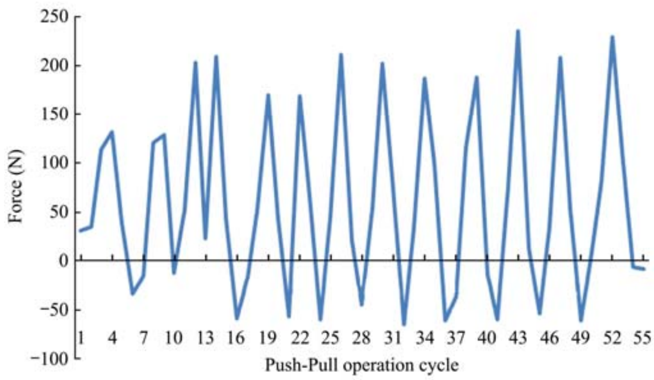

Figure 5 Push-pull force operation cycle in operation of single wheel hoe

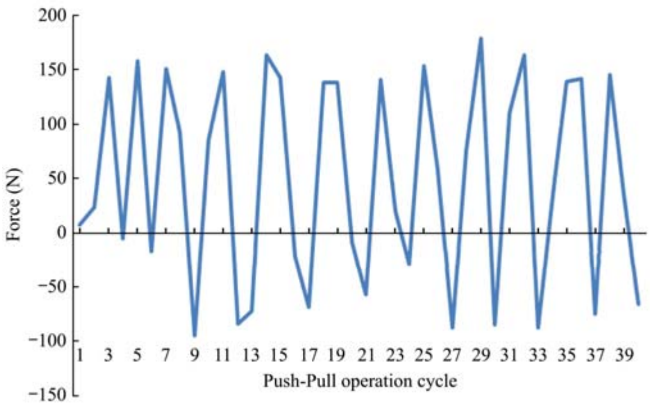

Figure 6 Push-pull force operation cycle in operation of four-wheel weeder

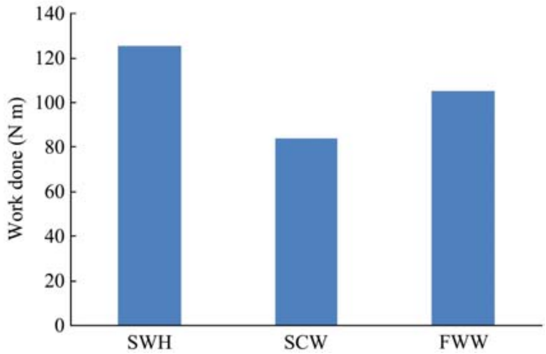

Figure 7 Work done in different type of weeding equipment in push operation

3 Results and discussions

The mathematical models developed for design of gender-friendly farm equipment was validated for force assessment, workdone and related machine parameters using measured data obtained in operation of single wheel hoe, cono-weeder and four-wheel weeder.

3.1 Validation of mathematical model for push - pull force determination

The resistance exerted by soil and weeds causes rapid push force increments before the point of soil failure. At a point where soil resistance force is overcome by an external pushing force, the force requirement decreases and reaches to zero. At the end of push operation, pull operation starts and extends up to maximum contraction of human elbow-grip length to attain the equilibrium position. Pulling is considered as idle operation, so, mainly frictional force needs to overcome to bring the equipment in equilibrium position. The applied force at handle (inclined 50 degree with horizontal) is distributed in two components one in horizontal i.e. F_x and another is vertical i.e., F_y, where F_x acts as cutting force of soil.

Push-pull operation causes rapid change in force requirements as shown in Figure 4-6 for cono-weeder, single wheel hoe and four wheel weeder respectively. The measured push force varies in each cycle of operation. Field test of cono-weeder shows the average measured push and pull forceswere118 and 40.6 N, respectively, as handle is inclined 50 degree with horizontal, the horizontal components of push and pull force F_{xpush} = 75.85 N, F_{xpull} = 26 N, respectively. Shakya (2016) also reported draft requirement of the cono-weeder which ranged from 122.4 to 274.5 N with an average value of 207.2 N. Nag and Nag (2004) also reported in their study that the force requirements in pulling or pushing modes with different kinds of manual weeders (projection finger weeder, V-blade hoe, Dutch hoe, blade and rake type, multiple sweep wheel type, wheel hoe type) were in range of 49.05to 196.2 N. The push and pull forces by the numerical methods predict were 77 and 32 N, respectively. Whereas in the average measured push and pull forces obtained in operation of four-wheel weeder were 162 and 56.58 N, respectively. Horizontal components of push force and pull force were F_{xpush} = 104 N, F_{xpull} = 36 N, respectively. The push and pull forces by the numerical methods predict were 114 N and 39.2 N, respectively. Similarly for single wheel hoe the average measured push and pull forces were 190 N and 39.81 N, respectively. Horizontal components of push force and pull forces were F_{xpush} = 122 N, F_{xpull} = 25 N, respectively. The push and pull forces predicted by numerical method were 86 N and 32 N, respectively.

Stability at static condition could be achieved by the design of equipment but in operational condition the dynamicity creates the machine unstable. Therefore dynamic stability was accounted by the application of push and pull forces during the operation. The mathematical Equations (7) to (14) show the parameters related to stability of equipment. Specific soil resistance (R) was considered 0.01 N mm^{-2} for depth of 50 mm based on Bernacki et al. (1985). In cono-weeder, the predicted force was 77 N that is very close to measured value of 75.84 N. Where in case of four wheel weeder the predicted force was 114 N and measured force requirement was 104 N, which is also near. In case of wheel hoe, the predicted force requirement was 86 N and measured force was 122 N. Observation was made that the slip angle of wheel hoe was significantly high in case of wheel hoe (about 30 degree), therefore the applied push force was distributed into two components, one along with X direction that is actual push force, another one is perpendicular to X direction that is side force. From the observed and predicted data of force in other two case of operation i.e., cono-weeder and four wheel weeder the negligible amount of side force appeared as the weeder followed the path of straight line during operation.

Table 1 Data related to force validation

Particulars	Values for different type of weeders		
	Cono-weeder	Single wheel hoe	Four-wheel weeder
Soil resistance (*R*) (N mm^{-2})	0.01	0.01	0.01
Coefficient of friction	0.4	0.4	0.4
Weight equipment (N)	80.0	80.0	98.0
Cutting width (mm)	150	180	250
Depth of operation (mm)	30	30	30
Predicted push force* (N)	77	86	114
Predicted pull force* (N)	32	32	39.2
Average measured push force (N)	118	190	162
Average measured pull force (N)	40.62	39.81	56.58
Range of measured push force (N)	15.7-137.4	8.2-235.7	7.2-178.8
Range of measured pull force (N)	9.1-73.4	5.1-64.94	5.2-87.3
Angle of push (°)	50	50	50
Normal force (Fn)	171.29	217	222

Note: * with developed model.

Table 2 Force and its direction in different plane

Particulars	Cono-weeder	Wheel hoe	Four-wheel weeder
Cutting force (N)	45	54	75
Frictional force (N)	32.0	32.0	39.2
Weight of weeder (N)	80.0	80.0	98.0
Force in x-direction (Fx)	Push force: 75.84 N Pull force: 26 N	Push force: 122 N 30° slip angle Actual force in x direction =105.7 N Pull force: 22.16 N	Push force: 104 N Pull force: 36.37 N
Force in y-direction (Fy)	90.39 N	137 N	124 N
Force in z-direction (Fz)	4.41 N No slip angle	3.18 N 30 degree slip angle	5.34 N No slip angle

The measured and predicted pull & push force values clearly indicated the practical situation of operation of these weeders. This may be due to dynamic condition of human being, type of weeders, weeding tool geometry and depth variation in field during operation, also due to many factors like soil characteristics, weed characteristics, foreign matters in soil, undulation surface etc. Out of three different types of weeders, the predicted values of push force were close to maximum push force measured in operation of four-wheel weeder and cono-weeder which is due to stability of equipment, swinging handle and almost fix depth of operation. While 45%variation in predicted and measured push forces was observed with single wheel hoe. This was due to fixed handle position for operation by a worker, inclusion of side force and slip angle, uneven depth of cut, soil surface etc. Slip angle of 30° was observed in operation of single wheel hoe that causes to add side force.

3.2 Validation of mathematical model for work done determination

For one complete cycle of operation the distance covered by the operator is due to the action of elbow flexion called as push and again elbow comes to its original position in contraction of elbow that is defined as a pulling operation. The work done was highest for single wheel hoe followed by four-wheel weeder and cono-weeder in a test field (Figure 7). On comparison of per unit cutting width, lowest workdone (gross) was found with four-wheel weeder followed by cono-weeder and single wheel hoe. Actual workdone calculated from developed equation also provided similar trend on per unit cutting width basis (Figure 8).

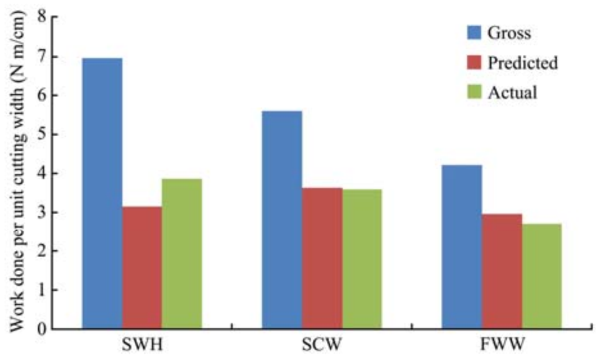

Figure 8 Workdone per cm cutting width in different type of weeding equipment in push operation

The time required per stroke with single wheel hoe, swinging type cono-weeder and four-wheel weeders was 1.254, 1.584 and 1.25 s, respectively. Corresponding, power required with predicted and actual values of work done was 45.19 & 55.54 W, 34.51 & 33.99 W and 59.28 & 54.08 W for single wheel hoe, cono-weeder and four wheel weeder, respectively (Figure 9). Data clearly indicated the power requirement for single wheel hoe was higher over predicted values whereas it was found lower over predicted value in case of four-wheel weeder. In case of single wheel hoe, the variations in actual power requirement with predicted value was due to fixed handle for its operation and minimum ground contact. This also indicates that conversion of power to actual work means more power is to be exerted by the operator for work in case of single wheel hoe with fixed handle. The power required by the operator is very close to predicted value in case of four-wheel weeder due to better mechanical efficiency.

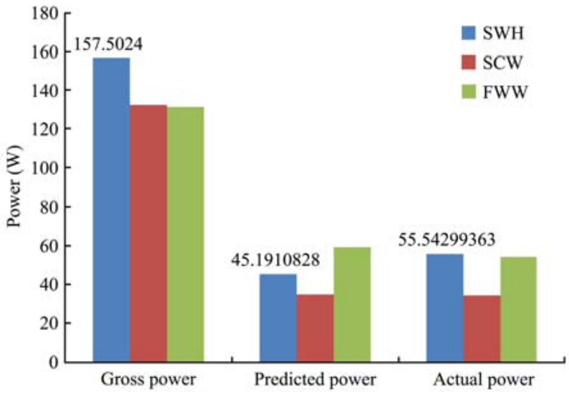

Figure 9 Predicted and actual power requirements in different weeders

3.3 Validation of mathematical model for determination of machine parameters

3.3.1 Handle height

Due to push-pull operation, handle must be swinging to adjust the instantaneous height of operation to apply force. The instantaneous height can be defined as

$$L = Y\cos\beta \quad (21)$$

where, Y is elbow length (m), and β is elbow angle to vertical plane (°).

During operation the instantaneous height varies based on the rotational angle covered by the operator. In design criteria, standard elbow height is considered as fixed height X for particular group of operators. Summation of standard elbow height (X) and instantaneous height (L) is total handle height.

$$H = X + Y\cos\beta \quad (22)$$

where, H is handle height (m); X: elbow height from ground (m); Y is elbow grip length (m) and β is elbow angle to vertical plane (°).

The survey data of summation of standard elbow height and instantaneous height of 95th percentile population are X = 0.98 m, Y = 0.3 m, respectively and maximum value of β is = 50°, therefore the total height of handle can be designed as

H = 0.98+0.3 sin 50

H = 1.20 m

3.3.2 Width of weeder handle

Design consideration of handle width provides range for width of handle for 5th and 95th percentiles of population. Normally U-type or T-type handle is used in manual operated farm equipment. U-type handle width can be managed by providing adjustment in its base width by knuckle joint. Whereas for width of T-type handle, 95th percentile bideltoid width can be considered.

3.4 Elbow angle vs hand force requirement at different distance

Force exerted by hand and elbow angle position has significant effect on the force application (Figure 10). The above figure shows that at different elbow angle, the applied force and covered distance are different in both pull and push operations. Elbow angle changes due to expansion and contraction of elbow. Maximum angle of 82 degree was made by elbow at maximum opening and minimum of 22 degree at maximum contraction of elbow. Figure 10 shows that the push- pull force also changes according to the elbow angle. Force exerted in pull operation is higher than force requirement in pull which is due to weeding and frictional resistance responsible against push force, on the other hand only frictional force is responsible for pulling force therefore pulling force is much less than push force in weeding operation.

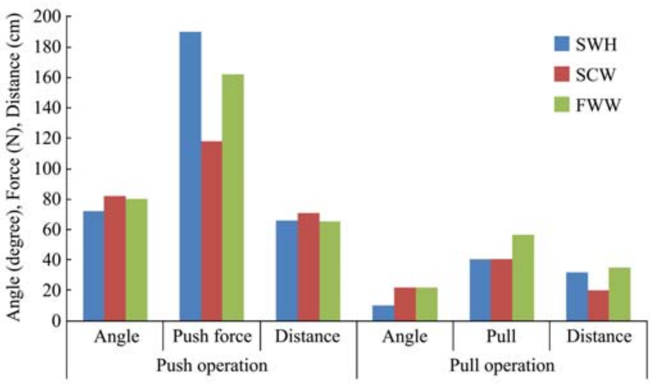

Figure 10 Effect of elbow angle on force at different distance

The validation of developed model clearly suggests for its applicability in field for designing a new weeder or refining/modifying existing weeder in terms of forces coming to the workers during operation, weeding tool position/geometry, avoiding slip angle, swinging type handle, balancing of equipment to reduce static loading etc.

4 Conclusions

The mathematical model developed for designing gender friendly weeder clearly indicates that there are significant influences of soil condition, equipment & tool geometry and human factors for achieving indented output with mechanical weeders. Total push force required can be managed as per involvement of type of workers by changing the depth of operation, width of cut and machine parameters. Force requirement, work done and machine stability are the factors that helps to define its human-machine relationship for optimum application of force to maximise the work done. Geometric design, soil condition, and ergonomics parameter of operation control the power requirements during the operation. Dynamic instability of the equipment is responsible for requirement of excess push force. The developed model will help in avoiding slip angle to overcome extra force required to push the equipment thereby benefiting to designer as well operators.

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