ISSN: 0256-6524

www.isae.in

Journal of Agricultural Engineering

VOL. 54, No. 4, October-December 2017

INDIAN SOCIETY OF AGRICULTURAL ENGINEERS

Journal of Agricultural Engineering

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Journal of Agricultural Engineering

Vol. 54 (4): October-December, 2017

Draft Prediction of Commonly Used Tillage Implements for Sandy Clay Loam Soil in India

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Article Info

Received : July, 2017
Revised
accepted : November, 2017

Key words: Soil bin, draft prediction equation, soil cone index, ASABE model, stepwise regression analysis

ABSTRACT

Draft requirements for prototypes of mouldboard plough, cultivator and offset disc harrow with different widths of cut or number of tools were measured at four levels of depth and four levels of forward speed in three soil compaction levels in a soil bin with sandy clay loam soil at an average soil moisture content of 9.58% (d.b.). Effect of depth was more significant on draft of mouldboard plough and offset disc harrow, whereas number of tynes was the most significant factor for cultivator. Rate of increase of draft with respect to depth was higher as compared to forward speed, cone index and width of cut for all implements tested. Draft values predicted by ASABE model were compared with those obtained from soil bin tests at three compaction levels. Quite often, the measured draft values were found to be about 2.9, 1.7 and 1.65 times more than the ASABE predicted values for mouldboard plough, cultivator and offset disk harrow, respectively. An equation similar to the ASABE model incorporating cone index was developed using stepwise regression analyses to model the draft of tillage implements for the range of soil and operating condition tested. Field tests with commercial models of these implements were conducted to acquire data for draft by developing appropriate instrumentation to validate the developed draft equation. The average absolute variations between the predicted and measured values of draft were within 5.5 % and 11.6% for all the implements tested, and thus validated the developed draft prediction equation.

Attempts have been made by various researchers around the globe to measure the draft requirements of various tillage implements, and to establish relationship between the draft and the factors affecting the draft (Clyde, 1936; Reed, 1937; Gill and Vanden Berg, 1968; Kydd *et al.*, 1984; Grisso *et al.*, 1996; Al-Janobi and Al-Suhaibani, 1998). The forward speed, depth of cut, width of cut, soil strength, moisture content, tool geometry and many other factors have been reported to be affecting the draft requirement of tillage implements. Many mathematical models have been developed for the draft prediction of tillage implements and their capability in predicting draft of implements was well documented (Collins *et al.*, 1978; Kepner *et al.*, 1978; Kydd *et al.*, 1984; Upadhyaya *et al.*, 1984; Harrigan and Rotz, 1995; Grisso *et al.*, 1996; ASABE, 2004).

ASABE Standards (2004) provide mathematical expressions for draft and a power requirement for tillage implement in several soil types, and is given as:

$$D = F_i\,(A + BS + CS^2)\,WT \qquad ...(1)$$

Where,

D = Implement draft, N,
F = Dimensionless soil texture adjustment parameter,
i = 1 for fine, 2 for medium, 3 for coarse textural soil,
A, B, C = Machine specific parameters,
S = Speed of operation, km.h^{-1},
W = Machine width, m, or number of rows or tools, and
T = Tillage depth, cm.

The coefficients are for a wide range of soil conditions, and consequently cannot be expected to yield accurate estimates for a given situation. ASABE Standard indicates an expected range of ±25% to ±50% for various tillage implements. Also, all draft data and equation for predicting draft presented in the Standards were based mostly on USA soils, and its applicability in Indian soil conditions has not been reported in literature. Presently, there is a shortage of data on draft requirements of agricultural implements in different soils of India. Therefore, the draft measurement as well as prediction is imperative for Indian soil conditions to generate draft data of various tillage implements. These data can serve as the basis for selecting tractors and implements for various farming operations under Indian conditions. But, collecting draft data under wide range of field conditions is a tedious job. Therefore, draft prediction models are required to be developed to generate draft data of implements under different soil and operating conditions. With this back ground, a study was undertaken at Indian Institute of Technology, Kharagpur, with the objectives to (a) measure draft requirement of commonly used tillage implements (mould board plough, cultivator, disc harrow) in sandy clay loam soil at varying operating and soil conditions in soil bin, (b) develop a model for draft prediction of tillage implements taking into consideration the parameters affecting it, (c) validate the developed model under field conditions.

MATERIALS AND METHODS

Laboratory Test

The main objective of the laboratory tests was to develop relationship between the draft of tillage implement and various parameters (implement, soil and operating) affecting it. The draft requirement of prototypes of mouldboard plough, cultivator and offset disc harrow were measured at different speeds, depths and soil cone index under controlled conditions in an indoor soil bin filled with sandy clay loam soil (57% sand, 20% silt, 23% clay). The detailed specification of the tillage implements are given in Table 1.

The soil bin comprised of a stationary bin, linear transmission system, implement and soil processing trolley, control unit and instrumentation for draft measurement (Fig. 1). The bin was 15.0 m long, 1.8 m wide and 0.6 m deep. Soil parameters as moisture content and cone index were measured to quantify the soil conditions. Cone index values were measured with a hydraulically operated instrumented cone penetrometer (ASABE Standards, 2004). Speed of operation was measured with a magnetic proximity switch (sensing distance: 11 mm; frequency: 1 kHz), fitted to the soil processing trolley and steel rods fixed at 500 mm apart along the side rail of the soil bin. The draft requirements of different tillage tools/ implements were measured using a calibrated extended octagonal ring transducer (EORT) (capacity: 5 kN, non-linearity: 0.05 %), and were recorded in a computer using a HBM Spider 8 data acquisition system (sampling rate: 1-9600 samples/s/channel; accuracy class: 0.05 %).

The tillage implements with different widths of cut/ number of tools were tested at three levels of soil conditions. All implements were tested at four levels of depth and four levels of speed of operation, Table 2. Experimental design was based on factorial RBD. The effects of implement, operating and soil parameters on drafts of these implements were determined in the laboratory tests at an average soil moisture content of 9.58% (d.b.). Any average cone index value located between the values considered for the design ±50 kPa was accepted as design value. Each test was replicated three times to ensure a reasonably consistent value of draft.

Field Test

In order to validate the developed draft prediction

Table 1. Technical specifications of prototype tillage implements

Tillage implement	Number of implement used	Specification
Mouldboard plough	3	Width of cut: 100, 150, 250 mm Type: General purpose
Cultivator	3	Type: Vertical rigid tyne No. of tynes : 1, 2, 3 Soil working tool type: Reversible shovel Shovel width: 50 mm Spacing: 230 mm
Offset disc harrow	3	No. of discs : 2, 3,4 Disc diameter: 330 mm Disc spacing : 125 mm Gang angle : 20°

Fig. 1: Experimental arrangement in soil bin

equation, one primary tillage implement (2×300 mm mould board plough) and two secondary tillage implements (9 x 235 mm cultivator and 1.6 m offset disc harrow) were used for evaluating draft requirements. All these were standard tillage implements used for seed bed preparation in India. The research plan for the field tests is given in Table 3. Experiments with the selected implements were conducted using a 31 kW Ford 3630, two-wheel drive tractor in experimental plots of Agricultural and Food Engineering Department, IIT,

Table 2. Research plan for laboratory tests

Implement	Variable		Level
	Independent variable		
Mouldboard plough	(i) Width of cut, mm	3	100, 150 and 250
	(ii) Cone index, kPa	3	≅700, ≅900 and ≅1200
	(iii) Depth of operation, mm	4	40, 80, 120 and 150
	(iv) Speed, km.h^{-1}	4	1.2, 2.2, 3.2 and 4.2
Cultivator	(i) Number of tynes	3	1, 2 and 3 tyne
	(ii) Cone index, kPa	3	≅500, ≅700 and ≅ 900
	(iii) Depth of operation, mm	4	40, 80, 120 and 150
	(iv) Speed, km.h^{-1}	4	1.2, 2.2, 3.2 and 4.2
Offset disc harrow	(i) width of cut, mm	3	320, 440, 550
	(ii) Cone index, kPa	3	≅400, ≅600 and ≅800
	(iii) Depth of operation, mm	4	40, 60, 80,100
	(iv) Speed, km.h^{-1}	4	1.2, 2.2, 3.2, 4.2
	Dependent variable		
	(i) Draft, N		

Table 3. Research plan for field tests

Implement	Variable	Level
	Independent variable	
Mouldboard plough	(i) Width of cut, m	0.6
	(ii) Speed, km.h^{-1}	in the range of 2.8 to 5.3
	(iii) Depth of operation, mm	100, 150, 200
	(iv) Cone index, kPa (Average)	1290 at 100 mm depth 1398 at 150 mm depth 1463 kPa at 200 mm depth
Cultivator	(i) No. of tyne	9
	(ii) Speed, km.h^{-1}	in the range of 4.1 to 6.4
	(iii) Depth of operation, mm	100, 140
	(iv) Cone index, kPa(Average)	964 at 100 mm depth 1053 at 140mm depth
Offset disc Harrow	(i) Width of cut, m	1.6
	(ii) Speed, km.h^{-1}	in the range of 4.0 to 7.2
	(iii) Depth of operation,mm	100, 120
	(iv) Cone index, kPa (Average)	526 at 100 mm depth 599 at 120 mm depth
	Dependent	
	(i) Draft, N	

Kharagpur. Before starting of the experiments with each implement; the data on bulk density, moisture content and cone index were collected.

The drafts of various prototype implements were measured using a developed instrumented three-point linkage (Fig. 2). Electrical strain gages of 350 Ω with a gage factor of 2.6 each were mounted on the body of lower links to measure the tensile and bending forces. A fabricated proving ring with mounted strain gauges attached to the top link was used to measure the compressive force acting during tillage operations. Three rotary potentiometers of 5 kΩ (Linearity: ±0.5 %) each were used for measuring the horizontal and vertical angles made by the lower links and the vertical angle made by the top link (Fig. 3). One of the potentiometer fixed on the rocker arm of the tractor hydraulic system was also used to measure the depth of tillage operation during draft measurement. During operation, data on forces acting on the links as well as the angles made by the links were acquired in different channels of a HBM Spider 8 data acquisition system at a frequency of 50 Hz, and were stored in a computer.

Knowing the forces acting on the links and the angles made by these links in horizontal and vertical planes, the draft of the implement was computed using the following expression:

$$D=F_a \cos\varnothing\cos\theta+F_b \sin\varnothing\cos\theta-F_c \cos\beta\cos\gamma \qquad ...(2)$$

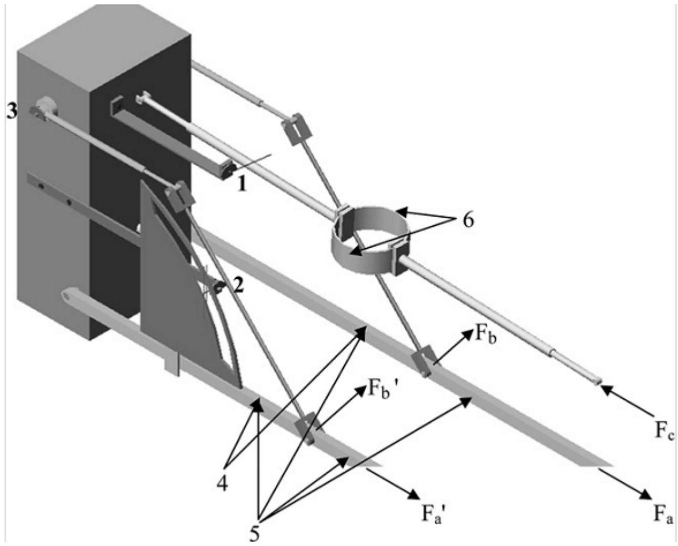
Where,

D = Implement draft, N,
F_a = Tensile force in lower link, N,
F_b = Bending force in lower link, N,
F_c = Compressive force in top link, N,
θ = Angle of lower link in horizontal plane, °,
φ = Angle of lower link in vertical plane, °,
β = Angle of top link in vertical plane, °, and
γ = Angle of top link in horizontal plane, °.

Each test was replicated three times.

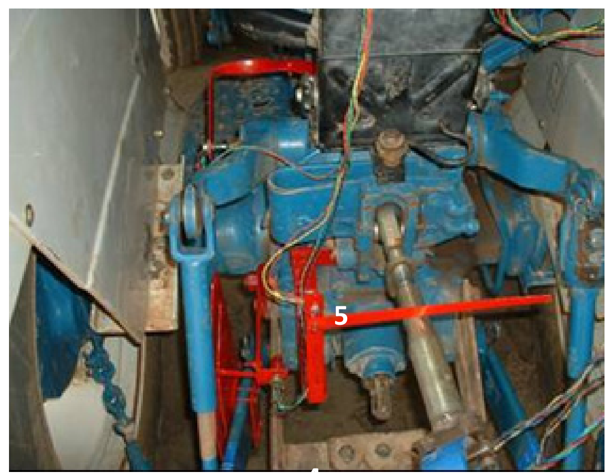
Statistical Analysis and Procedure

Analysis of the data obtained was carried out using SAS 9.3 software package (SAS Institute Inc., Cary, NC, USA) to understand the effect of speed (S), depth (T), width (W) and cone index (CI) on draft of



(1) Vertical angle for top link(2) Horizontal angle for lower link (3) Vertical angle for lower link (4) Strain gauge positions for axial force (5) Strain gauge positions for bending force (6) Strain gauge positions for top link compressive force

Fig. 2: Instrumented three-point linkage for measurement of force and angle of links



1. Top link 2. Lower link 3. Lower link vertical angle 4. Lower link horizontal angle 5. Top link vertical angle

Fig. 3: Instrumentation for measurement of forces on the link and link angle of tractor

implements as well as development of draft prediction model. Stepwise regression analysis was performed to determine the coefficients of the variables. Means were compared using LS mean technique. Statistical significance was evaluated at the $P < 0.05$ level.

RESULTS AND DISCUSSION

Draft of Tillage Implement

Mouldboard plough

Analysis of variance (ANOVA) of the data on draft of mouldboard plough indicated that the individual effects of S, T, W and CI and their interactions on the draft were significant at 1% level (Table 4). The effect of depth on the draft had highest influence than that of cone index, width and speed, in that order. Draft of mouldboard plough increased with increase in speed, depth, width of cut and cone index. The relationship of draft with width of cut, cone index, depth and speed of operation is shown in Fig. 4.

It was found from the best fit curves that the speed had quadratic effect on draft, which is well in accordance with the findings of earlier researchers (Kepner *et al.*,

Table 4. ANOVA for draft of tillage implements

		Mouldboard plough		Cultivator		Offset disc harrow	
Source of variation	**df**	**MS**	**F Value**	**MS**	**F Value**	**MS**	**F Value**
S	3	4849366.14	127866.0*	4644567.81	412063.00*	1162590.62	77048.70*
T	3	32657268.68	861096.0*	23512468.65	2086012.00*	17056285.70	1130376.00*
W	2	8832865.24	232902.0*	25705618.25	2280587.00*	7912123.60	524362.00*
CI	2	11830996.79	311956.0*	4361545.49	386954.00*	2408092.20	159592.00*
S×T	9	252014.56	6645.0*	245652.31	21794.10*	34758.32	2303.55*
S×W	6	82904.24	2185.9*	294717.00	26147.10*	41055.20	2720.86*
S×CI	6	68978.40	1818.8*	31215.79	2769.45*	9612.13	637.03*
T ×W	6	136217.24	3591.7*	1337297.81	118644.00*	273846.12	18148.70*
T ×CI	6	478678.77	12621.6*	182034.45	16150.00*	39426.32	2612.91*
W×CI	4	167548.82	4417.8*	331454.24	29406.40*	15476.89	1025.70*
W×CI×S	12	8694.44	229.2*	5287.97	469.15*	4548.07	301.42*
W×CI×T	12	21121.32	556.9*	28331.58	2513.56*	6050.24	400.97*
W×S×T	18	6350.50	167.4*	22217.47	1971.12*	6163.46	408.47*
CI×S×T	18	13053.31	344.2*	11747.74	1042.25*	1999.75	132.53*
W×CI×S×T	36	6458.64	170.3*	5623.92	498.95*	1738.01	115.18*
Error	288	37.90		11.30		15.09	

*df: degrees of freedom; MS: mean square; *significant at 1% level*

1978; Summers *et al.,* 1986; ASABE, 2004). Summers *et al.* (1986) conducted their experiments in clay loam and silt loam soil with 6×410 mm mould board plough in the speed range of 6.5 to 9.5 km.h^{-1} and 140 to 220 mm depth of operation. ASABE (2004) is valid for all types of soil, implements and operating conditions. It was also noticed that the rate of increase in draft with speed was faster at higher values of speed than at the lower ones. This could be due to higher shear rate and increased soil-metal friction at higher forward speed.

Cultivator

The draft of single, double and three tyne cultivator showed that all the independent variables as well as their interactions had significant effect on draft. The number of soil working tools was the most significant factor on the variation of draft, followed by the depth, speed and cone index in that order. The relationship of draft with number of soil working tools, cone index, depth and speed of operation is shown in Fig. 5. The general trend showed that draft values of cultivator increased with increase in speed, working depth, number of tynes (width of cut) and soil cone index. The relationship between the drafts of cultivator with speed was linear at most of the combinations of selected variables. The behaviour was similar to the findings of Payne and Tanner (1959), Dransfield *et al.* (1964), Glancey *et al.* (1996), Grisso *et al.* (1996), Al-Janobi and Al-Suhaibani (1998) and Sahu (2005) for the drafts of cultivator and chisel plough. Payne and Tanner (1959) carried out their experiments with a vertical blade of 25 mm width in the speed range of 0.2 to 2.7 m.s^{-1} in clay, clay loam and sandy loam soil. Glancey *et al.* (1996) did their experiments in loam and clay soil with a 9-tyne cultivator up to a depth of 229 mm between a speed ranges of 0.8 km.h^{-1} to 7.2 km.h^{1}. Al-Janobi and Al-Suhaibani (1998) carried out the experiments in loamy sand with a harrow having 36 discs. Implement was operated between 3 km.h^{-1} to 9 km.h^{-1} and depth of operation was maintained between 100 mm to 200 mm. Sahu (2005) conducted the experiments in sandy clay loam soil with a 9 tyne cultivator.

The rate of change of draft with speed increased up to 80 mm of depth of operation, then decreased till 120 mm and again increased up to 150 mm depth of operation. These results are in agreement with the findings of Sohne (1956) that at lower depth the exposed length of curved surface of the tyne was more. Thus, shear stresses were imposed on the soil as it flowed up the curved surface. The increasing trend

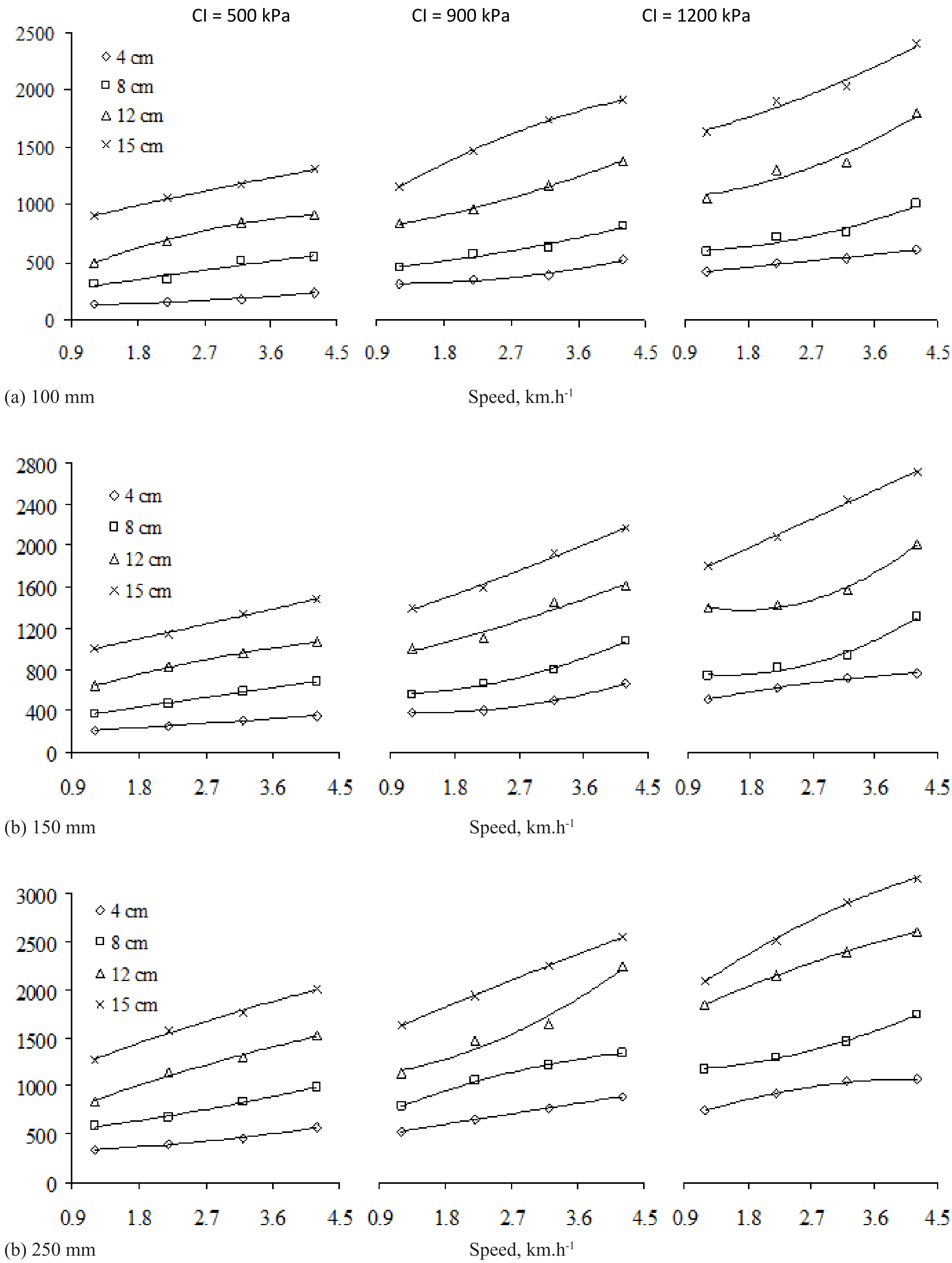


Fig. 4: Relationship between draft of mouldboard plough with width of cut, cone index, depth and speed of operation

for the rate of change of draft with increasing depth of operation from 120 mm to 150 mm could be attributed to the consolidation effect of soil profile.

Offset disc harrow

The individual effects of S, T, W and CI and their interactions on the draft were significant at 1% level. Depth of operation was the most significant factor on the variation of draft, followed by width of cut, cone index and speed of operation in that order. The relationship of draft with width of cut, cone index, depth and speed of operation is shown in Fig. 6. The general trend showed that draft values of offset disc harrow increased with increase in speed and depth of operation, and the relation varied from quadratic to linear. However, in most of the plots, the relation was linear. This behaviour also agreed with the findings of Kepner *et al.* (1978), Gill *et al.* (1980), Bloome *et al.* (1983), Sommer *et al.* (1983), Kydd *et al.* (1984), Summers *et al.* (1986), Singh (1993), Grisso *et al.* (1996), Sahu (2005) and Serrano and Peca (2008) who reported that the drafts of disc plough and harrow increased with the depth and speed of operation for a given soil. Grisso *et al.* (1996) conducted field trials in silty clay loam soil with a tandem disc harrow having 4.9 m working width. Implement was operated within the depth of 51 mm to 127 mm and speed ranges from 4.8 to 9.7 $km.h^{-1}$ Serrano and Peca (2008) carried out their field experiments in clay and sandy clay loam soil with disc harrow having number of disc varying from 20 to 36. Experiments were carried out at speed between 3 $km.h^{-1}$ to 9 $km.h^{-1}$. The rate of change of draft with increase in soil cone index was almost similar for all depths of operation, forward speeds and widths of cut. It appeared that there were not much dynamic effects associated with increase in cone index of soil during the operation of the disc harrow.

Suitability of ASABE Model for Predicting Draft of Indian Tillage Implements

ASABE draft prediction model is accepted as an international standard prescribed for a wide range of tillage implements and several soil types. For predicting draft under different soil conditions, ASABE model categorizes soil as fine, medium and coarse rather than traditional soil textural classification. Fine textured soils are described as predominantly clayey, medium textured soils being loamy and sandy soil as coarse textured soil.

Soil texture adjustment parameter value, F_i in the ASABE draft prediction model, simply implies the comparison of draft requirement of implement when operating in soil of classified group. According to the ASABE recommendation, sandy clay loam soil was considered as a medium textured soil for calculation of draft. Machine and soil parameters for the implement provided in ASABE standard (2004) were used for prediction. As ASABE model does not consider cone index as a direct parameter, same draft values obtained for different soil cone index values were compared with the measured draft data. The comparison between the predicted and measured values of draft for mouldboard plough, cultivator and disc harrow at different cone indices are presented in Fig. 7 (a, b, c).

It can be seen from Fig. 7 (a, b, c) that even though the coefficient of determination of the best fit lines for all the implements at different cone indices was reasonable (0.74 to 0.99), the slope of the best fit line varied from 0.61 to 0.92, 0.79 to 1.04 and 0.69 to 0.81 for mouldboard plough, cultivator and disc harrow, respectively. With increase in cone index, the slope deviated more from unity for the implements tested. For all cases, MSD was exceptionally high and increased with increase in cone index, except for cultivator. Increase in cone index from 500 kPa to 700 kPa, MSD in case of cultivator first decreased, and again increased with increase of cone index from 700 kPa to 900 kPa. The percentage variation between the predicted and measured draft values of mould board plough varied from (-) 39.3 % to 68.3 %, (-) 23.1 % to 135.3 %, and 13.4 % to 189.2 % at cone index of 500 kPa, 900 kPa and 1200 kPa, respectively. Similarly, the percentage variation between the predicted and measured draft value of cultivator was (-) 57.6 % to 13.7 %, (-) 47.0 % to 54.4 %, and (-) 23.0 % to 66.9 % at cone index of 500 kPa, 700 kPa and 900 kPa, respectively; whereas the variation for disc harrow was (-) 16.8 % to 24.7 %, (-) 1.8 % to 40.7 %, and 30.2 % to 65.0 % at cone index of 400 kPa, 600 kPa and 800 kPa, respectively. ASABE Standard indicated an expected range of ±40 %, ±30 %, and ±30% in draft prediction for mould board plough, cultivator and offset disc harrow, respectively.

For the implements tested, the range of variation of draft values prescribed by ASABE standard was thus exceeded in the present study. It was also noticed that the variation in draft of all implements tested increased with increase in cone index. Hence, it was concluded that the applicability of ASABE draft prediction model was poor for the soil conditions and implements tried in the present study.

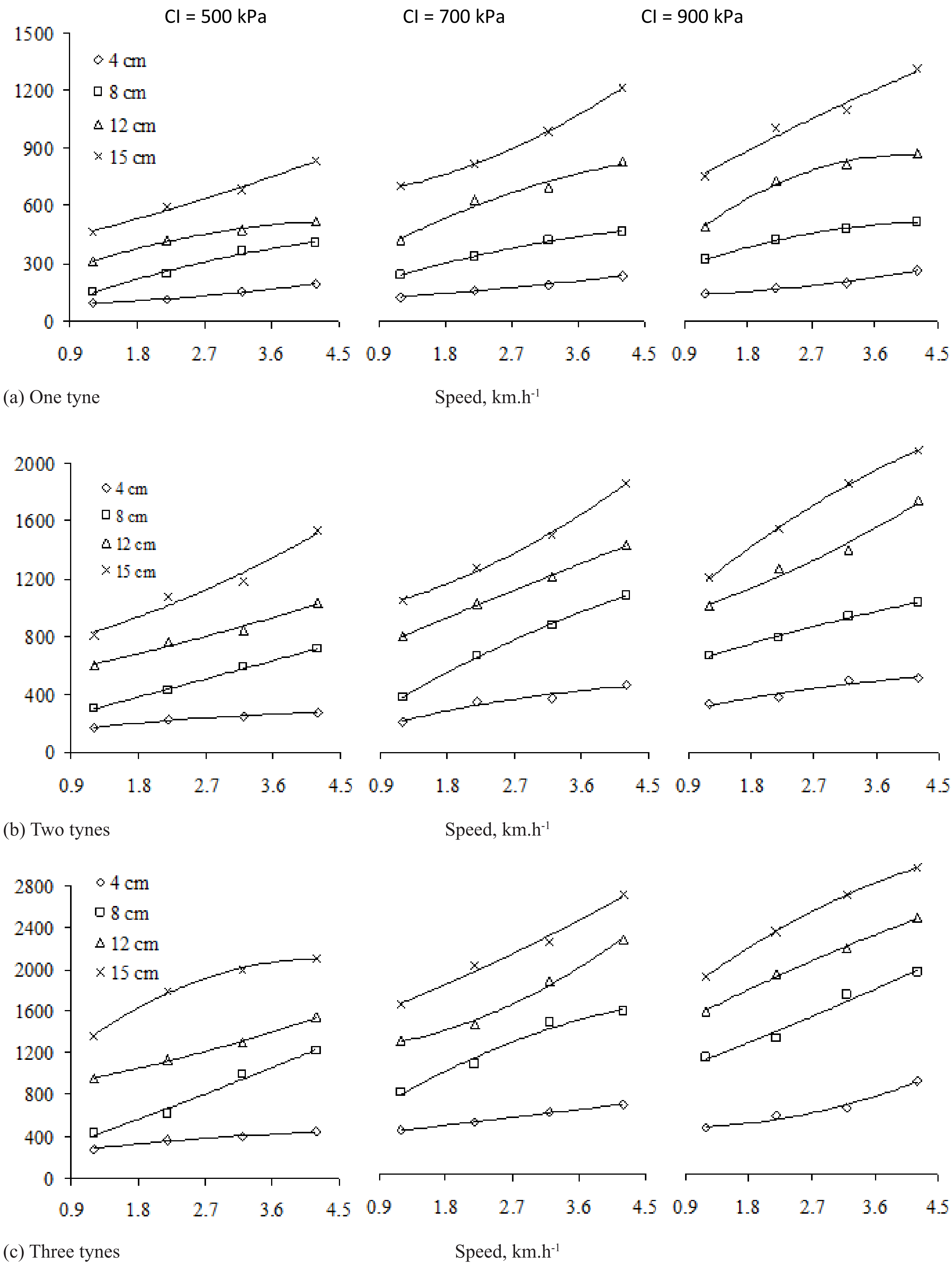


Fig. 5: Relationship between draft of cultivator and width of cut, cone index, depth of operation and forward speed

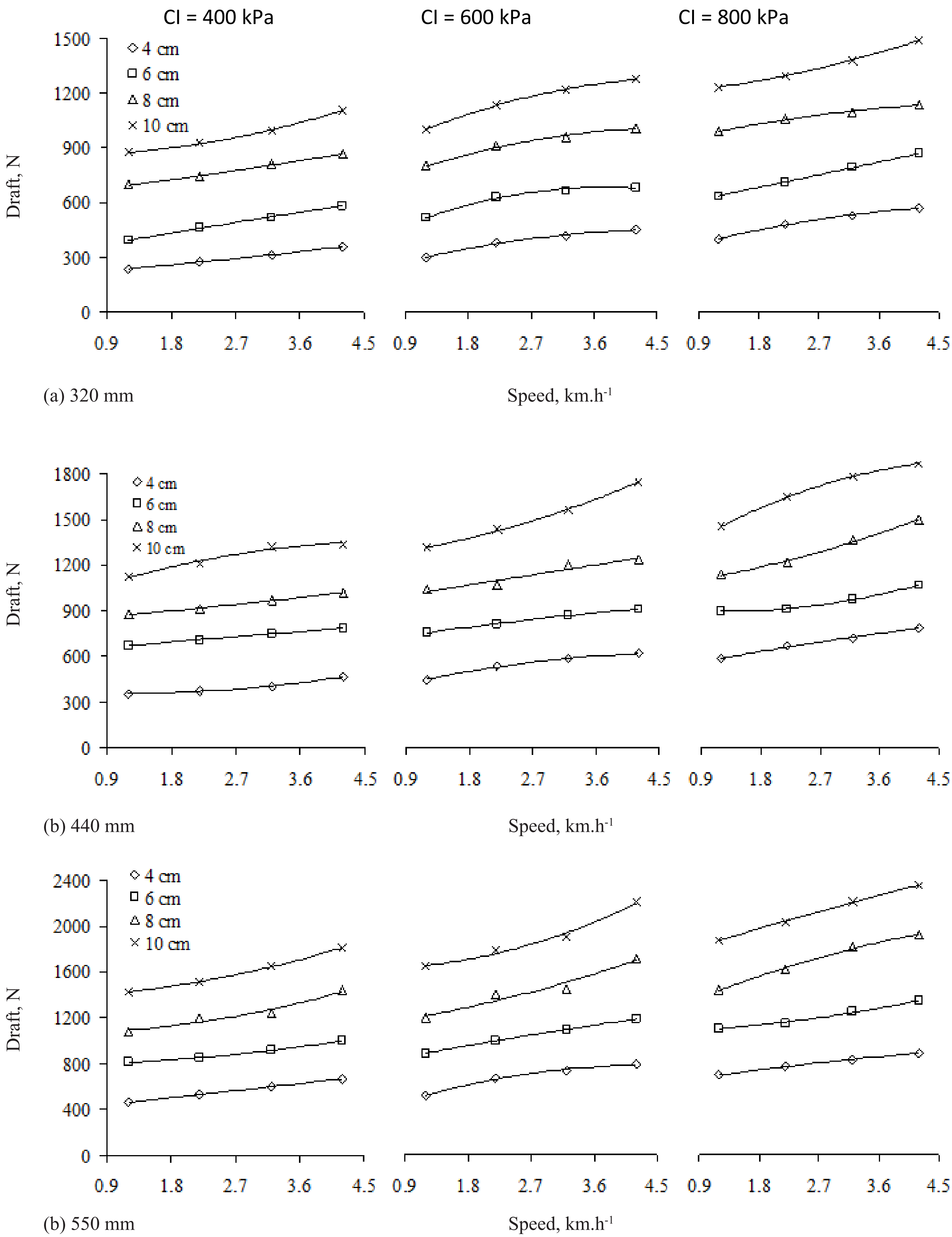
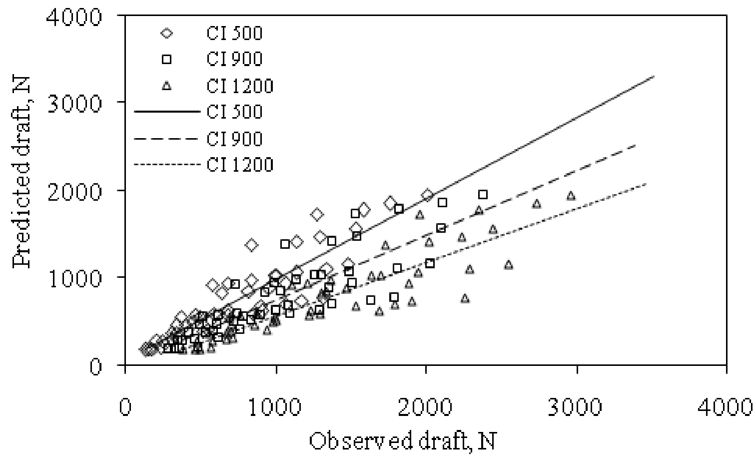
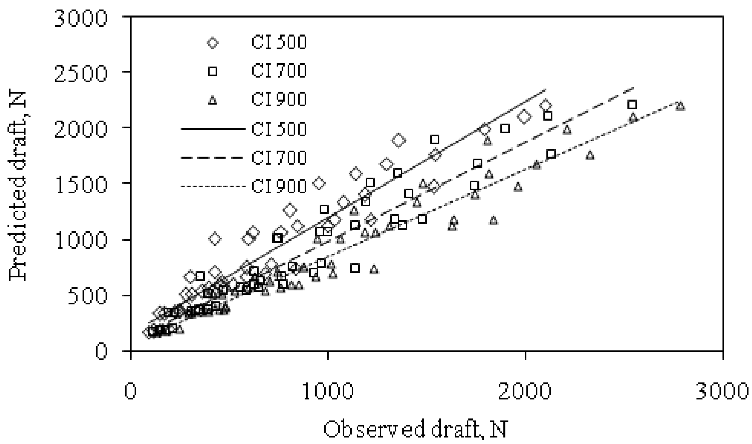


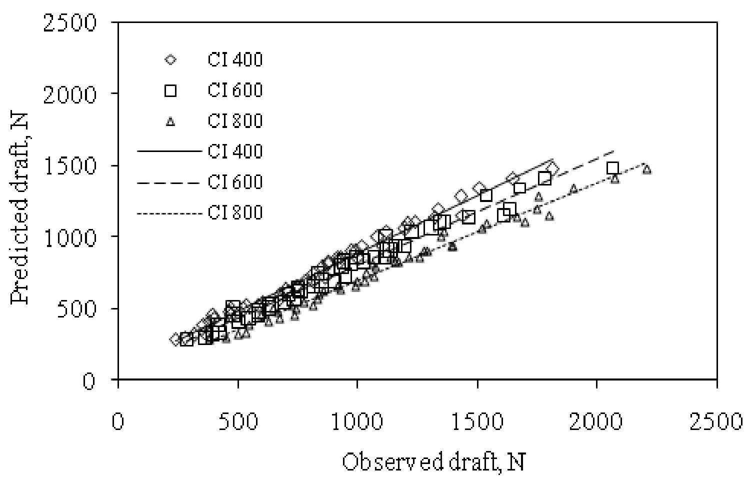
Fig. 6: Relationship between draft of offset disc harrow and width of cut, cone index, depth of operation and forward speed



(a) Mouldboard plough



(b)Cultivator



(c) Offset disc harrow

Fig. 7: Comparison of observed and predicted draft values for tillage implements

Developments of Draft Prediction Model for Tillage Implements

As ASABE standard does not consider the cone index parameter in the draft prediction equation, a simple equation similar to the ASABE model incorporating cone index was proposed to model the draft of tillage implements where draft was a function of the implement width, soil cone index, depth and speed of operation. The equation for the selected tillage implements was developed using stepwise regression technique from the data obtained in the laboratory tests at different depths, operating speeds and soil conditions, and is represented as given below:

$$D= (ACI+BS+CS^2)\ WT \qquad \ldots(3)$$

Where,

D = Implement draft, N,
A, B, C = Machine specific parameters,
A = *f* (soil strength),
B, C = *f* (soil bulk density),
CI = Cone index, kPa,
S = Speed of operation, $km.h^{-1}$,
W = Machine width, m, or number of rows or tools, and
T = Tillage depth, cm.

The boundary condition for the model prediction is the upper and lower value of the independent variables considered during laboratory and field experiments. The upper and lower values of the independent variables are mentioned in Table 2 and 3.

The major effort in developing the model was determination of the machine specific parameters A, B and C. Each parameter was a function of tillage tool. The regression coefficients determined from the analysis were the coefficients of Eq. 3, and are presented in Table 5.

The values of R^2 of the model (0.86 to 0.98) for the draft data obtained from soil bin tests indicated that the experimental data fitted the regression well. It was noticed from the values of different coefficients in Table 5 that the cone index interaction with width and depth (CI×W×T) was the significant factor influencing the draft of all tillage implements tested. Besides the CI term, S^2 term also contributed towards the draft of mould board plough and cultivator (Kepner *et al.*, 1978; Summers *et al.,*1986) for mould board plough; ASABE, 2004 for both), whereas S term contributed towards the draft of cultivator and offset disc harrow (ASABE, 2004). The effect of S^2 term affected the draft of cultivator significantly, which was not in accordance with ASABE standard. One possible explanation for this observation could be the existence of inertia effect on the draft of cultivator due to the presence of curvature in the shovel type of tynes tested.

Validation of the Developed Draft Model for Tillage Implements

The predicted draft values for different tillage implements were obtained with the input parameters tried during the field tests. The actual and predicted values of draft for the tillage implements were compared (Table 6).

A close agreement between observed and predicted values of draft was found with a slope of 0.96, 1.04 and 1.10, and coefficient of determination as 0.99, 0.91 and 0.88 for mouldboard plough, cultivator and offset disc harrow, respectively. The percent variation between predicted and observed draft values for

Table 5. Results of stepwise regression analysis for draft of tillage implements

Tillage implement	Variable Coefficient	CI×W×T A	S×W×T B	S^2×W×T C	Model R^2	Model MSE
Mouldboard	Parameter Estimate	0.42	0.00#	16.40	0.86	51762.0
Plough	Standard Error	0.01		0.88		
Cultivator	Parameter Estimate	0.04	5.50	0.40	0.98	8950.0
	Standard Error	0.001	0.66	0.13		
Offset disc	Parameter Estimate	0.32	37.96	0.00	0.95	9408.5
harrow	Standard Error	0.006	1.14			

#*The coefficients are entered as zero when found statistically not significant at 5 percent level*

Table 6. Statistical analysis for model validation and comparison

Implement		Mouldboard plough		Cultivator		Offset disc harrow	
Model		Developed	ASABE	Developed	ASABE	Developed	ASABE
Percentage variation	Max	8.50	50.40	9.80	37.30	-1.30	29.70
	Min	-2.40	31.00	-13.50	29.00	-19.80	13.70
R^2		0.99	0.87	0.91	0.96	0.88	0.62
Slope		0.96	0.57	1.04	0.66	1.10	0.80
MSD		0.18	11.98	0.41	8.31	0.51	1.74

mouldboard plough, cultivator and offset disc harrow were found to be (-) 2.4 % to 8.5 %, (-) 13.5 % to 9.8 %, and (-) 19.8 % to (-) 1.3%, respectively. These variations were considered to be acceptable considering the variations in existing soil condition as well as the normal experimental errors incurred while measuring the draft values.

Comparison between Developed and ASABE Draft Model

To calculate draft using the ASABE draft prediction equation, sandy clay loam soil was considered to be medium textured soil. The comparison between the developed and ASABE draft models was made, (Fig. 8 (a, b, c), Table 6) with reference to the observed draft data during field testing of mouldboard plough, cultivator and offset disc harrow.

It was noticed from Fig. 8 that even though the coefficient of determination for the ASABE draft model for mould board plough and cultivator was high, the slopes of the best-fit lines for both these equations (0.57 for mould board plough and 0.66 for cultivator) were far away from unity. For offset disc harrow, though the slope of the best fit line was reasonable (0.80), the coefficient of determination (0.62) was low. It could also be seen from Table 6 that the MSD value for prediction with ASABE draft model for the implements was high as compared to the developed model. The percent variations between the ASABE predicted and measured draft values varied between 31.0 % and 50.4 %, 29.0 % and 37.3 %, 13.7 % and 29.7 % for mould board plough, cultivator and offset disc harrow, respectively, and were high as compared to within (-) 19.8 % to 9.8 % for the developed equation. Thus, it could be concluded that the Eq. 3 can predict the draft requirement of selected tillage implements operating in sandy clay loam soil at any soil cone index under any combination of width, speed and depth of operation.

CONCLUSIONS

Implement draft was found to increase with increase in cone index, width of cut/number of soil working elements, speed and depth of operation for mouldboard plough, cultivator and offset disc harrow.

The relationship between draft and depth of operation, implement forward speed was found to be quadratic for both mouldboard plough and cultivator as compared to a linear relationship for offset disc harrow. The relationship between draft and soil cone index, width of cut was found to be almost linear for all the implements tested.

The percentage variation between the observed and predicted draft values using ASABE equation for mouldboard plough, cultivator and offset disc harrow was found to be (-) 39.3 to 189.2, (-) 57.6 to 66.9 and (-) 16.8 to 65.0, respectively at different levels of cone index. At higher cone index values, the draft prediction further deteriorated, indicating poor applicability of ASABE equation for draft prediction under the experimental conditions.

The developed model could predict the draft requirements of mouldboard plough, cultivator and offset disc harrow in sandy clay loam soil at different soil compactions at an average (absolute) variation of 5.5%, 11.6% and 10.5%, respectively.

The results of investigation carried out would provide useful information for designing and selecting suitable tillage implement for better power utilization in sandy clay loam soil.

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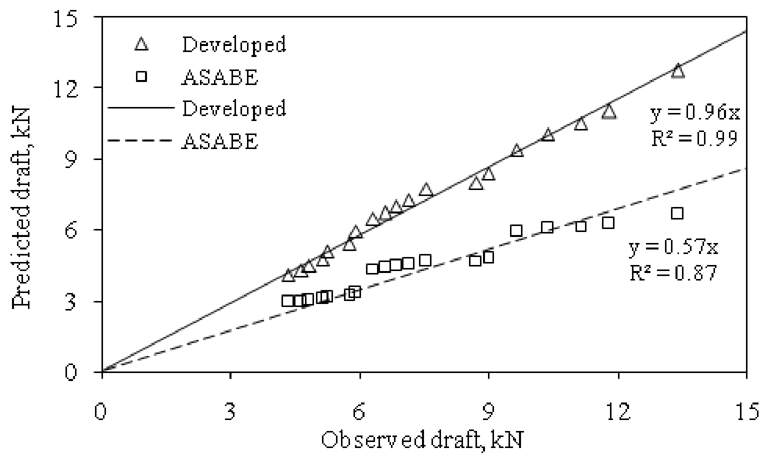
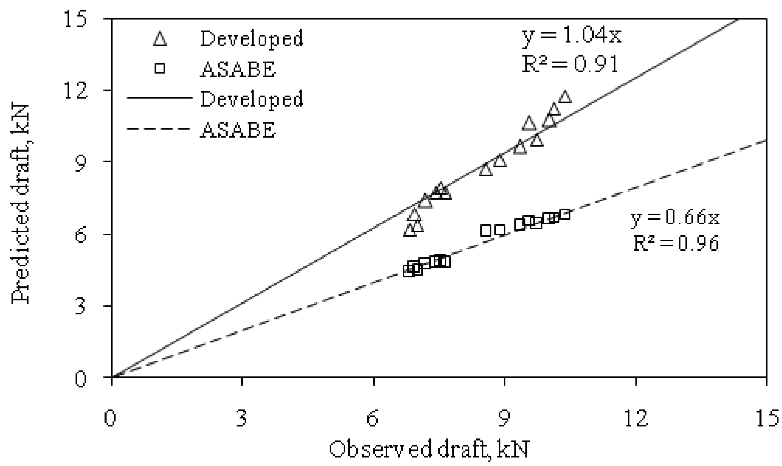
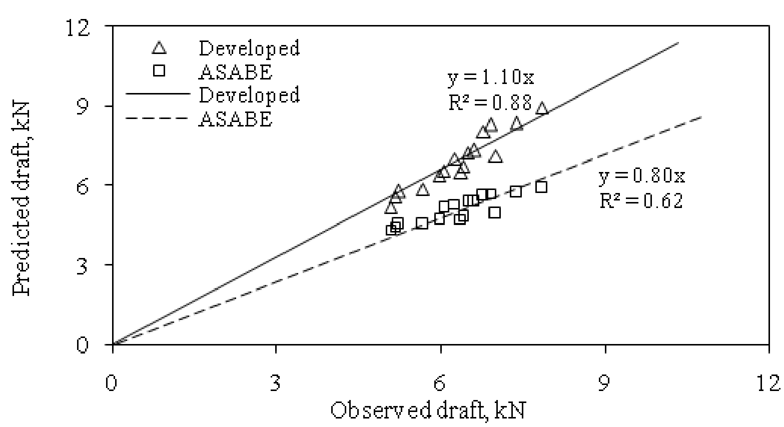


(a) Mouldboard plough



(b) Cultivator



(c) Offset disc harrow

Fig. 8: Comparison of observed and predicted draft values based on two draft models

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Journal of Agricultural Engineering

Vol. 54 (4): October-December, 2017

Compatibility Analysis of Control Arrangement for Some Indian Tractors

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Article Info

Received : March, 2016
Revised accepted : November, 2017

Key words: Tractor workplace, anthropometric data, biomechanical dimensions

ABSTRACT

A good tractor design requires that important controls are easily accessible to the operator. Tractor operator controls within the workplace should be conveniently and logically located, and the workplace should fit both tall and short operators. The design parameters of the tractor workplace configuration were determined by using anthropometric dimensions of male tractor operators of Gujarat region. The locations of different tractor seat and control locations were calculated considering the biomechanical and anthropometric measurements. Studies on evaluation of the design location of controls resulted in steering column angle of 65^{o} with horizontal, foot pedals distance of 875 mm from SRP and the draft control lever distance of 286 mm from SRP. Compatibility analysis was done with five Indian tractors. It was found that the workplace dimensions of selected tractors varied widely with the design values.

Proper design of controls is important for comfortable and safe operation of tractors. The workplace should be so located on the machine that the visibility in the driving position is good without requiring the operator to work in awkward or tiring position. Levers, pedals and instruments should be conveniently and logically located, and the workplace should fit both tall and short operators.

The placement of controls in the tractor operator workplace is a complex task for the designer, who must take into account the anthropometric characteristics of the target population. If the operators' controls are not properly adapted to his anatomy, the performance demanded of him may quickly reach and even exceed the limits of tolerance. As a result of excessive stress, premature fatigue and imposed health, the possibility of accidents will increase. Therefore, greater emphasis is required to adopt the operating controls to the physical convenience of the human operator. Moreover, there should be uniformity in placement of these controls on all available tractor models in order to accommodate the operators leading to efficient and comfortable operation.

Anthropometric data are primary data used in the design of tractor workplace. Liljedahl *et al*. (1959) emphasized the need for the design of the tractor workplace based on operators' anthropometric and biomechanical characteristics. Gite and Yadav (1989) had compiled the anthropometric data of agricultural workers from central India, and suggested use of the data for farm machinery design on the basis of 5th, 50th and 95th percentile values of the dimensions. Yadav and Tewari (1998) reviewed tractor operator workplace designs, and suggested that the tractor seat and locations of various hand- and foot-operated controls should be designed to accommodate 90% of the driver population. Tewari *et al*. (2007) concluded that anthropometric data of agricultural workers are essential for the safe and efficient design of farm machinery. The anthropometric design of workplaces, location of controls, size of control panel, design of safety belt, seat size, and orientation of foot pedal etc. would reduce occupational injury and enhance operator safety. Pheasant and Harris (1982) studied the biomechanical factors which influence human strength in the operation of a pedal. They investigated the pedal position with respect to Seat Reference Point (SRP), and concluded that ideally pedal location should be 12.5% stature below SRP and 47.5% in front of SRP to have a better driving posture and optimum force application. Arude *et al*. (1999) studied the locations of the existing controls in some popular Indian tractor models and tractor operator's activities from the driver seat while performing ploughing operation. A significant difference in placement of clutch, brake, hydraulic control lever, steering wheel and foot rest from the SRP in the tractor work place of the different models was observed. Mehta *et al*. (2007) investigated that the anthropometric dimensions of agricultural workers need to be taken into consideration for design of seat height, seat pan width, seat pan length, seat backrest width and seat backrest height, respectively, of a tractor. The seat dimensions recommended for tractor operator's comfort based on anthropometric data of 5434 Indian male agricultural workers were as follows: seat height of 380 mm, seat pan width of 420–450 mm, seat backrest width of 380–400 mm (bottom) and 270–290 mm (top), seat pan length of 370±10 mm, seat pan tilt of 5^0–7° backward and seat backrest height of 350 mm. Madan *et al*. (2008)studied the existing location of controls like brake pedal, clutch pedal, hydraulic control lever, hand accelerator, foot rest and gear lever in selected farm tractors; and measured the forward horizontal distance, vertical distance and lateral horizontal distance from SRP. They concluded that the locations of main controls such as clutch, brake, hydraulic control lever in the workspace of tractor varied widely in different models of Indian tractors studied. Kumar *et al*. (2009) compared the location of controls with workspace envelopes and the BIS: 12343 standards for commonly used tractors on Indian farms. They revealed that controls are located in areas defined by BIS: 12343 standards in some tractors, but these were not placed in the workspace envelopes of the Indian population. This resulted in a mismatch between the workspaces envelope and location of controls as defined by the standard. The controls needed a complete change in their layout in the workspace envelopes, as this could not be achieved by providing seat movement in the horizontal and vertical directions in the present tractor designs. The seat should have provision for horizontal and vertical movement to accommodate the maximum population for comfortable operation of the tractor controls once they are located within the workspace envelopes. Pajnoo *et al*. (2012) found out the most comfortable combination of angle of steering wheel and its horizontal and vertical distances from SRP in proportion to the stature of majority of Indian tractor operators for enhancing their capabilities of turning the steering wheel. The study revealed that the steering wheel angle of 20^0 to 25^0 with vertical axis along with a horizontal and vertical position of 39 % to 42 % and 30 % of the stature of an operator, respectively, enables him to apply a maximum force of 77.5 Nm to 79.5 Nm for operating the steering wheel. Yadav (1995) reported mean frequencies of 72, 148, 230 and 436 for operation of clutch pedal, brake pedals, draft control lever and viewing backward, respectively, by the tractor drivers over a period of one hour. Madan *et al*. (2008) studied the frequency of operation of controls like brake pedal, clutch pedal, hydraulic control lever, hand accelerator, foot rest and gear lever in selected farm tractors, while doing field operations for 15 min with different farm implements. The average frequency of operation of clutch pedal for M. B. plough, disc plough, disc harrow and tiller was the same. Clutch pedal was operated only once for all the operations, whereas the average frequency of operation of the brake pedal for 15 minutes interval was 9, 13, 14 and 14, respectively, for above mentioned implements. Frequencies for hydraulic control lever operation for different operators were in the range of 18-26, 25-38, 26- 37 and 2-3, respectively. Inclusion of ergonomic design considerations for tractor workplace can increase the efficiency, comfort and safety of operator.

The present research work was carried out to study the workplace configurations of selected tractors, and compute efficient configuration of tractor workplace and controls for Indian tractor operators based on anthropometry.

MATERIALS AND METHODS

Workplace Configuration Design Considerations

Anthropometric data

The design of an efficient workplace configuration should be done by considering the anthropometric data of user's population. For the present study, anthropometric data of randomly selected 734 tractor operators of Gujarat (Anon., 2005) were used, Table 1. The anthropometric data of male agricultural workers of Gujarat as well as of Indian population is given in Table 1. These data were comparable to the Indian population (male agricultural workers) of 12 states as compiled by Gite *et al*. (2009), and thus represented Indian population.

Biomechanical model equations

The anthropometric data were used to calculate different configurations for safe and comfortable ride on tractor. The equations derived from biomechanical model (Yadav *et al*., 2000) as shown in Fig. 1 was used to calculate the design values for the efficient location of controls for the tractor operators.

Table 1. Anthropometric data of male agricultural workers of Gujarat and Indian population

Sl. No.	Dimension	Gujarat 5th	Gujarat 50th	Gujarat 95th	Gujarat SD	India 5th	India 50th	India 95th	India SD
1.	Stature, mm	1524.40	1631.20	1738.00	64.60	1521	1633	1746	68
2.	Weight, kg	39.24	55.25	71.26	9.73	40.4	54.7	68.9	8.7
3.	Grip diameter (inside), mm	42.40	50.70	59.10	5.10	39	48	57	6
4.	Shoulder breadth, mm	382.70	431.20	479.70	29.50	361	416	471	33
5.	Arm reach from the wall, mm	760.20	833.20	906.20	44.40	756	838	921	50
6.	Shoulder grip length, mm	639.00	774.80	706.90	41.30	628	723	818	58
7.	Foot length, mm	225.50	247.40	269.30	13.30	160	184	208	15
8.	Sitting height, mm	737.10	808.30	879.50	43.30	744	830	916	52
9.	Sitting eye height, mm	643.90	712.40	780.80	41.60	640	726	812	52
10.	Sitting shoulder height, mm	502.30	556.80	611.40	33.20	492	568	645	47
11.	Elbow rest height, mm	161.80	196.10	230.50	20.90	162	214	266	32
12.	Knee height sitting, mm	449.90	504.10	558.40	33.00	444	504	563	36
13.	Sitting popliteal height, mm	394.90	441.10	487.30	28.10	367	417	468	31
14.	Buttock popliteal length, mm	400.10	446.70	493.30	28.30	382	442	486	37
15.	Buttock knee length, mm	455.90	528.20	600.40	43.90	476	536	596	36
16.	Functional leg length, mm	870.80	930.20	989.60	36.10	881	978	1076	59
17.	Thigh clearance height sitting, mm	108.10	132.50	157.00	14.80	92	129	165	22
18.	Hip breadth sitting, mm	274.70	320.10	365.40	27.60	258	311	364	32
19.	Sitting acromial height, mm	500.00	557.00	615.00	35.00	492	568	645	47
20.	Forearm hand length, mm	418.10	456.10	494.00	23.10	404	453	503	30
21.	Hand length, mm	155.80	176.80	197.80	12.80	160	178	197	11

Source: Anon. (2005); Gite et al. (2009)

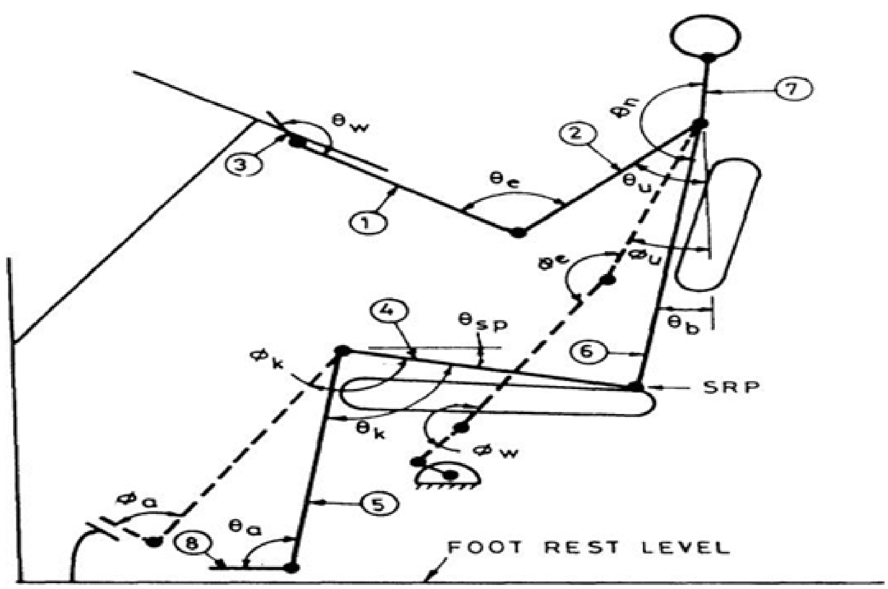


Fig. 1: Typical link-joint biomechanical model of seated tractor operator

The equations derived from the model are:

Horizontal distance of hand operated controls from SRP

$$= (L_{fa} - 0.5\ L_h)\ Sin\ (\Phi_e - \Phi_u) + L_e\ Sin\ (\Phi_u) - H_s\ Sin\ (\theta_b) + (L_h/2)\ Sin\ (\Phi_w + \Phi_e - \Phi_u - \pi) + 0.07H_{st} \quad \ldots(1)$$

Vertical distance of hand operated controls from SRP

$$= H_s\ Cos\ (\theta_b) - L_e\ Cos\ (\Phi_u) + (L_{fa} - 0.5\ L_h)\ Cos\ (\Phi_e - \Phi_u) + (L_h/2)\ Cos\ (\Phi_w + \Phi_e - \Phi_u - \pi) + 0.043H_{st} \quad \ldots(2)$$

Horizontal distance of foot control from SRP

$$= L_p Cos\ (\theta_{sp}) + H_p\ Sin\ ((\phi_k + \theta_{sp} - \pi/2) + (L_f/2)\ Cos\ (\phi_k + \theta_{sp} - \phi_a) + 0.07\ H_{st} \quad \ldots(3)$$

Vertical distance of foot control from SRP

$$= H_s Cos(\theta_b)\ - L_e\ Cos(\theta_u) + (L_{fa} - 0.5\ L_h)\ Cos(\theta_e - \theta_u) + (L_h/2)\ Cos(\theta_w + \theta_e - \theta_u - \pi) + 0.043H_{st} \quad \ldots(4)$$

Horizontal distance of steering wheel from SRP

$$= (L_{fa} - 0.5\ L_h)\ Sin\ (\theta_e - \theta_u) + L_e\ Sin\ (\theta_u) - H_s\ Sin\ (\theta_b) + (L_h/2)\ Sin\ (\theta_w + \theta_e - \theta_u - \pi) + 0.07H_{st} \quad \ldots(5)$$

Vertical distance of steering wheel from SRP

$$= H_s\ Cos\ (\theta_b) - L_e\ Cos\ (\theta_u) + (L_{fa} - 0.5\ L_h)\ Cos\ (\theta_e - \theta_u) + (L_h/2)\ Cos\ (\theta_w + \theta_e - \theta_u - \pi) + 0.043H_{st} \quad \ldots(6)$$

Where,

L_{fa} = Forearm hand length, mm,

L_h = Hand length, mm,

L_e = Shoulder elbow length, mm,

H_s = Shoulder height (sitting), mm,

H_{st} = Stature, mm,

Φ_a = Ankle angle for foot resting on undepressed clutch/ brake, degree,

θ_b = Back angle from vertical, degree,

θ_c = Elbow angle for operation of steering wheel, degree,

Φ_c = Elbow angle for operation of draft control lever in lowest position, degree,

θ_k = Knee angle for foot resting on foot rest, degree,

Φ_k = Knee angle for foot resting on undepressed clutch/ brake pedal, degree,

θ_u = Upper arm angle from vertical for steering wheel operation, degree,

Φ_u =Upper arm angle from vertical for draft control lever operation in lowest position, degree,

θ_{sp} = Seat pan angle from horizontal, degree,

θ_w = Wrist angle for steering wheel operation, degree,

Φ_w = Wrist angle for draft control lever operation in lowest position, degree, and

θ_n = Angle between neck and spine links, degree.

The locations of the tractor controls were determined considering the biomechanical and anthropometric measurements. The anthropometric data (Table 1), comfort angle between links (Table 2) and link length (Table 3) were used to calculate the design values by using Eqns. 1 - 6.

Tractor Workspace Control Measurement

Five different popular models of Indian tractors of different makes and sizes; viz TM_1 (40.56 PS), TM_2 (40.56 PS), TM_3 (45.62 PS), TM_4 (35.49 PS) and TM_5 (25.35 PS) were randomly selected for the study (Table 4). The horizontal, vertical and lateral distances of the various controls were measured in stationary condition with the tractor on level ground using a tape, scale and protractor with the SRP as the base point. SRP is defined as the point in the central longitudinal plane of seat where the tangential plane of the lower backrest and horizontal plane intersect. At the time of measurement, the seat was positioned in the middle of its adjustment range, both vertically and horizontally and at the mid-point of its suspension travel.

A comparison was made between the selected tractor workplace configurations with the IS 12343:1998, and also with the design values to evaluate the efficiency of tractor workplace among the different selected tractor models. The Indian Standard (IS 12343:1998) lay down a range of dimensions as shown in Fig. 2 for the operator's seat and location of specific controls relative to the SIP within the seating accommodation on agricultural tractor with a track width greater than 1150 mm. The values obtained from the selected tractor workplace configurations should be nearer to design values for higher efficiency and comfort.

Table 2. Range of comfort and angle used in design of tractor operator workplace

Sl. No.	Body member	Angle range, degree	Angle used in design, degree	Comments
1.	Back	(θ_b) 20-30	10	
2.	Hips	(θ_h) 95-120	95	
3.	Knee	(θ_k) 95-136	95	For foot resting on foot rest
		(Φ_k)	120	Foot pedal operation
4.	Ankle	(θ_a) 90-110	90	
		(Φ_a)	90	
5.	Upper arm	(θ_u) 10-45	45	For steering control
		(Φ_u)	15	For hydraulic control
6.	Elbow	(θ_e) 80-120	120	For steering control
		(Φ_e)	160	For hydraulic control
7.	Wrist	(θ_w) 170-190	170	For steering control
		(Φ_w)	170	For hydraulic control
8.	Seat pan angle from horizontal	(θ_{sp}) NA	3	
9.	Seat backrest angle	(θ_{ls}) NA	25	
10.	Angle between neck and spine links	(θ_n) NA	180	

Source: Rebiffe (1969)

Table 3. Length of links in terms of anthropometric measurements

Link	Link length in terms of anthropometric measurement, cm
Forearm link	Forearm hand length (L_{fa}) - Hand length (L_h)
Upper arm link	Shoulder elbow length(L_e)
Hand link	Hand length (L_h) x 0.5
Thigh link	Buttock-popliteal length (L_p) x 0.8
Shank link	Popliteal height (H_p) x 0.8
Spine link	Sitting shoulder height (H_s)
Neck link	(Sitting eye height (H_{eh}) - H_s) x 0.5
Foot link	Foot length (L_f) x 0.5

RESULTS AND DISCUSSION

Design of Efficient Configuration of Controls

The computed locations of controls for the 50th percentile was considered as the design values (Table 5), which showed that the difference in vertical distance of controls for the 5th to 95th percentile tractor operators stature varied from a minimum of 4.5 mm (for hydraulic control) to a maximum of 111.2 mm (for steering wheel). The difference in horizontal distance of controls for the 5th to 95th percentile tractor operators stature varied from a minimum of 36.1 mm (for hydraulic control) to a maximum of 170.0 mm (for clutch and brake pedal). Therefore, in order to accommodate the 5th to 95th percentile tractor operator stature, provision of 111.2 (or, 112) mm vertical and 170 mm horizontal adjustment in seat was desirable. The designed value of steering column angle using anthropometric data was 65 degrees.

Workplace Configurations of Selected Tractor Models

The workplace configurations of the selected tractor models are given in Table 5. Wide variations were found in the case of dimensions of steering column angle, position of hydraulic control lever, horizontal and vertical distance of clutch and brake pedal from SRP. The range of horizontal, vertical and lateral distances of the various controls with respect to SRP of the selected tractor models are shown in Fig. 3.

Comparison of Selected Tractor Workplace Configurations with BIS 12343:1998

The comparison of selected tractor workplace configurations with the standard for Indian tractors as given by BIS IS 12343:1998 was done, and the results are presented in the Fig. 4 (a) and (b). The measurements were taken with respect to SRP, but for comparison SIP was calculated and compared with BIS IS 12343:1998.

The horizontal distance of steering wheel centre from

Table 4. Detail specifications of tractor models under study

Sl. No.	Particular	Tractor model				
		TM_1	TM_2	TM_3	TM_4	TM_5
1.	Year of manufacture	2005	1999	2008	2004	2000
2.	Metric horsepower, PS	40.56	25.35	45.62	35.49	25.35
3.	Engine rated speed, rpm	2300	1900	2300	2000	2100
4.	Engine					
	a. No. of Cylinder	3	2	3	3	2
	b. Cooling system	Water cooled	Water cooled	Water cooled	Water cooled	Water cooled
4.	Tyre					
	a. Rear	12.4 x 28, 12 PR	12.4 x 28, 8 PR	13.6 x 28, 12 PR	12.4 x 28, 12 PR	12.4 x 28, 12 PR
	b. Front	6.0 x 16, 8PR	6.0 x 16, 8PR	6.0 x 16, 8PR	6.0 x 16, 8PR	6.0 x 16, 8PR
5.	Unballast mass	1790 kg	1760 kg	1825 kg	1580 kg	1850 kg
6.	Overall length	3335 mm	3120 mm	3335 mm	3010 mm	3420 mm
7.	Overall width	1650 mm	1685 mm	1650 mm	1650 mm	1680 mm
8.	Ground clearance	430 mm	360 mm	400 mm	320 mm	380 mm

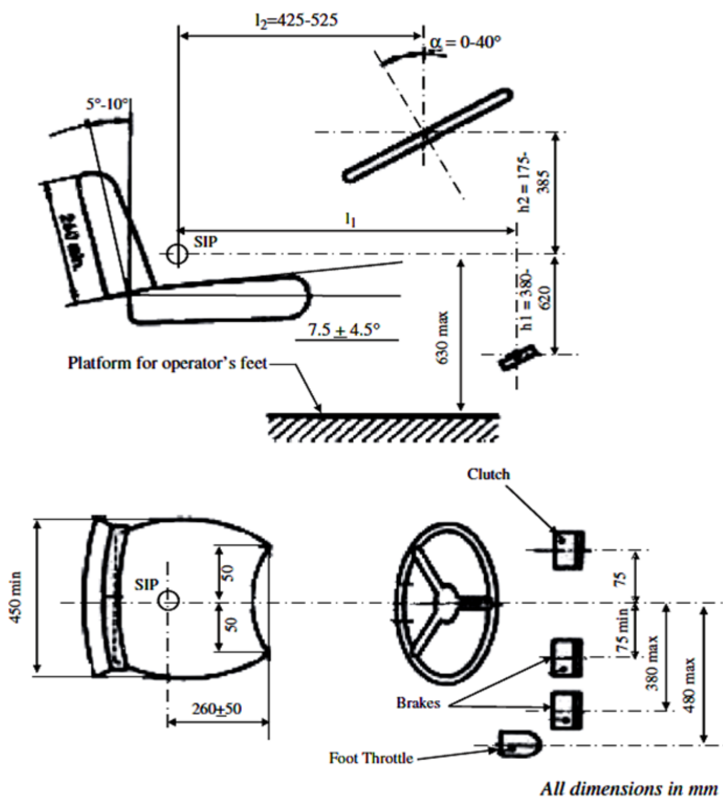


Fig. 2: Operator's seating accommodation (BISIS 12343:1998)

Table 5. Placement of tractor operator controls in selected Indian tractors

Sl. No.	Particulars	Tractor model					Mean	C.V.
		TM_1	TM_2	TM_3	TM_4	TM_5		
1.	Steering wheel							
	i) Steering column angle from horizontal, deg.	50.0	65.0	65.0	75.0	65.0	64.0	12.5
	ii) Horizontal distance of steering wheel centre from SRP, mm	560.0	720.0	540.0	660.0	640.0	600.0	154.0
	iii) Vertical clearance of steering wheel centre from SRP, mm	245.0	230.0	265.0	50.0	130.0	184.0	443.3
2.	Foot control							
	a) Clutch							
	i) Horizontal distance from SRP, mm	720.0	670.0	740.0	635.0	600.0	653.0	101.8
	ii) Vertical clearance from SRP, mm	-360.0	-370.0	-360.0	-490.0	-390.0	394.0	124.9
	b) Brake							
	i) Horizontal distance from SRP, mm	700.0	660.0	730.0	600.0	710.0	680.0	67.7
	ii) Vertical clearance from SRP, mm	-350.0	-400.0	-360.0	-560.0	-480.0	430.0	184.9
3.	Foot rest height from SRP, mm	-550.0	-570.0	-540.0	-660.0	-560.0	576.0	74.9
4.	Hydraulic control lever							
	i) Horizontal clearance from SRP, mm	330.0	280.0	285.0	290.0	495.0	336.0	242.4
	ii) Vertical clearance from SRP, mm	-210.0	-170.0	70.0	170.0	100.0	144.0	355.7
5.	Horizontal distance of seat edge from steering wheel edge, mm	250.0	900.0	250.0	1000.0	350.0	550.0	600.2
6.	Vertical distance of seat edge from steering wheel edge, mm	105.0	150.0	180.0	100.0	125.0	132.0	225.4
7.	Steering column height, mm	800.0	720.0	750.0	880.0	820.0	794.0	70.1
8.	Steering wheel angle with vertical, degrees	32.0	15.0	18.0	20.0	25.0	22.0	27.1
9.	Clutch pedal angle, degrees	55.0	75.0	68.0	25.0	50.0	54.6	31.7
10.	Seat backrest angle, degrees	12.0	15.0	12.0	15.0	23.0	15.4	26.2
11.	Horizontal distance of clutch from steering wheel centre line, mm	260.0	250.0	260.5	240.0	260.0	255.0	35.1
12.	Horizontal distance of first brake from steering wheel centre line, mm	240.0	325.0	250.0	230.0	255.0	260.0	129.3
13.	Horizontal distance of second brake from steering wheel centre line, mm	360.0	360.0	365.0	360.0	310.0	351.0	58.7
14.	Horizontal distance of accelerator pedal from steering wheel centre line, mm	210.0	380.0	230.0	400.0	380.0	320.0	256.9
15.	Steering wheel diameter, mm	450.0	455.0	410.0	440.0	440.0	439.0	35.6
16.	Foot rest to pedal height, mm	190.0	190.0	200.0	200.0	185.0	193.0	31.1

Note: Distance measured below and rear of SRP is considered negative.

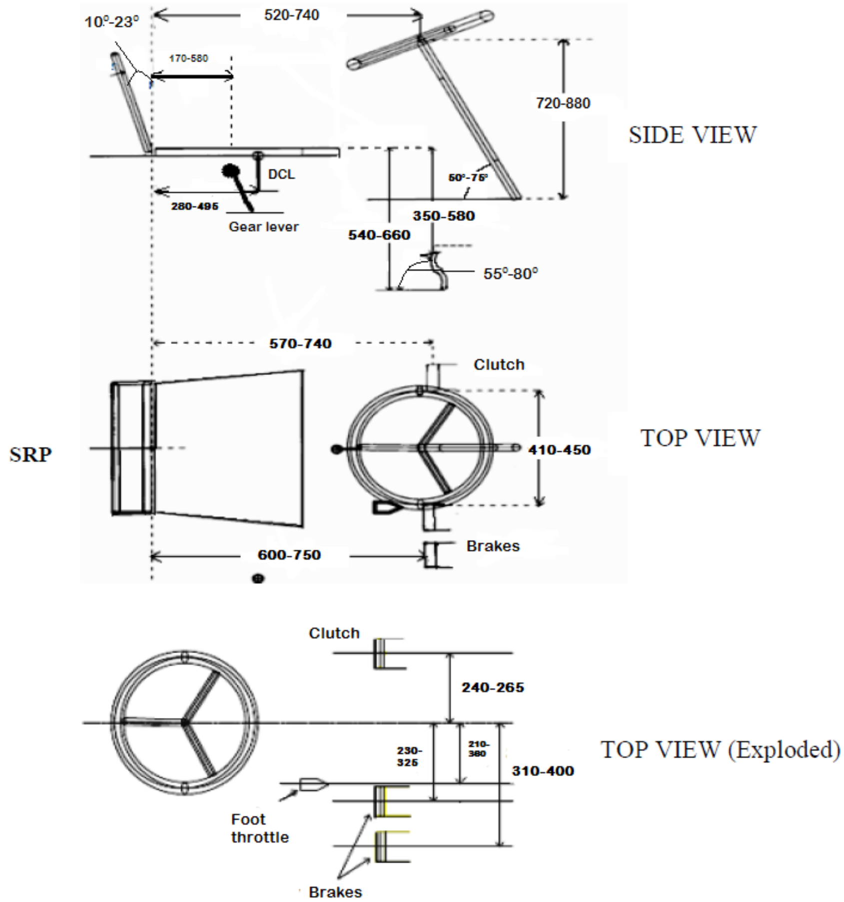
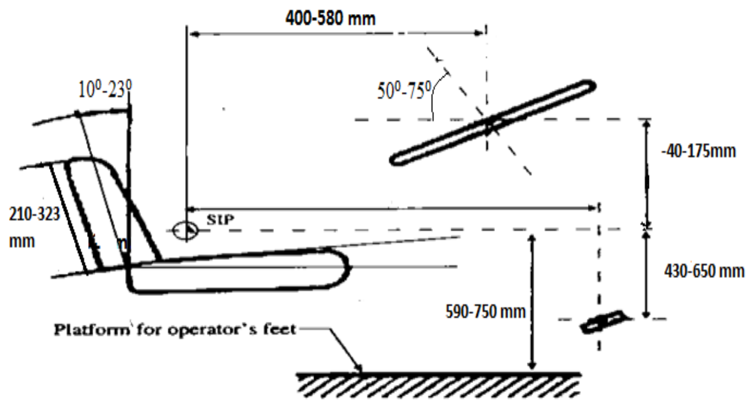


Fig. 3: Horizontal, vertical and lateral distance of controls from SRP in selected tractors

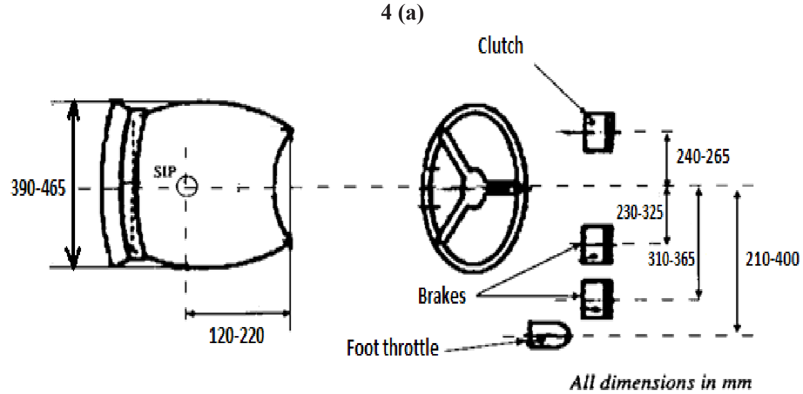
SIP in tractor models TM_1, TM_2, TM_3, TM_4 and TM_5, were in the range of 400-580 mm, indicating that these conformed with the IS standard. The steering column angle was in the range of 50^0-75^0. Only the tractor model TM_1 had the steering column angle in the range as described in the standard, while in all other tractor models it differed widely with the maximum value (75^0) in the model TM_4. Therefore, it may cause difficulty in turning of steering wheel. The vertical distances of steering wheel centre from SIP varied from (-) 40 mm to 175 mm. The value was negative for the model TM_4; while for TM_1, TM_2 and TM_5 it was less than the value prescribed by the standard. The position of steering wheel relative to SIP is mainly dependent on the angle of the upper arms to the torso and the angle between the upper and lower arms. The steering column angle is affected by the seating position, steering wheel diameter and the force required for turning the steering wheel. It was found that vertical location of steering column was not in the prescribed range for all tractors, which indicates discomfort of operator's seating posture as well as in the steering movement.

The footrest height ranged from 590 mm 750 mm was prescribed by the IS standard for all selected tractor workplace configurations. For all the selected tractor models, the horizontal distance of seat edge from SIP was found to be lower than the prescribed range as defined by the standard. It was found 180 mm for TM_1, 150 mm for TM_2, 220 mm for TM_3, 120 mm for TM_4 and 135 mm for TM_5. The vertical distance of brake pedal from SIP varied from 430-650 mm, and was in accordance with the Indian standard. The lateral distance of clutch pedal from SIP ranged from 240-265 mm, and for first brake pedal it varied from 230-325 mm. For second brake pedal it varied from 310-365 mm. These were in the prescribed range for all tractors. Lateral distance of foot throttle ranged from 210-400 mm, and was also in the prescribed range for all tractors.

According to the BIS standard, the seat backrest inclination should be in the range of 10^0- 15^0. The



4 (a)



4 (b)

Fig. 4: Location of controls in selected tractor workplace configurations with respect to IS 12343: 1998

values for the selected tractor models were in the range of 10^0-23^0, and exceeded (23^0) in the case of the model TM_5. The seat backrest height was found to vary from 210-328 mm, and was lower than the prescribed value for TM_4 and TM_5 model. The seat pan width of the tractor models ranged from 390-465 mm; and was below the prescribed range of 460 mm in the model TM_1, TM_3, TM_4 and TM_5.

It is thus evident that many controls of the selected tractors were not located within the optimum workspace envelope as described in the Indian standard, and some even exceeded the limit of the maximum area of the workspace envelope. Therefore, an operator presently has to adopt uncomfortable postures and stretch his limits of normal reach to operate the controls. Frequently used controls as foot brake, clutch, accelerator, depth and draft control lever needed proper placement for convenient operation and do not cause excessive stress on the operator.

Therefore, it could be concluded that the location of controls of tractor models (TM_1, TM_3) were within the prescribed range, while the tractor models (TM_2, TM_4, TM_5) did not match tractor workplace specifications with the prescribed values of the BIS standard. Similar results were reported by Kumar *et al*. (2009) and Mehta *et al*. (2011).They reported similar findings for some tractor models on the location of controls like steering, foot clutch, foot brake and foot accelerator that were not located in areas designated by the BIS 12343 standard.

Comparison of Selected Tractor Workplace Configurations with Design Values

The design values given in Table 6 were compared with the configurations of selected tractor workplaces, and are presented in Table 7. The design values were (a) steering angle of 65^0, (b) foot pedals (clutch and brake) distance of 875 mm from SRP, and (c) draft control lever distance of 286 mm from SRP for Indian operators.

Table 6 indicated that the steering column angle of the selected tractor models needed to be shifted by (+) 15.0°, 0.0°, 0.0°, (-) 10.0°, and (+) 1.0° with respect to the configurations of TM_1, TM_2, TM_3, TM_4, and TM_5, respectively. Clutch pedal location was required to be

Table 6. Design values of tractor workplace based on anthropometry and bio-mechanical model

Sl. No.	Parameter	Design value for percentile[a]			Range
		5th	50th	95th	
1.	Steering wheel				
	i) Horizontal distance of steering wheel centre from SRP, mm	659.4	723.3	732.1	72.7
	ii) Vertical clearance of steering wheel centre from SRP, mm	440.3	487.9	551.5	111.2
2.	Foot control				
	a) Clutch				
	i) Horizontal distance from SRP, mm	791.0	876.5	961.7	170.0
	ii) Vertical clearance from SRP, mm	(-)340.3	(-)378.2	(-)415.9	75.6
	b) Brake				
	i) Horizontal distance from SRP, mm	791.0	876.5	961.7	170.0
	ii) Vertical clearance from SRP, mm	(-)340.3	(-)378.2	(-)415.9	75.6
3.	Foot rest height from SRP, mm	(-)579.0	(-)554.0	(-)529.0	50.0
4.	Hydraulic control lever				
	i) Horizontal clearance from SRP, mm	269.1	286.2	305.2	36.1
	ii) Vertical clearance from SRP, mm	(-)147.3	(-)142.4	(-)151.8	4.5

[a] *The figures in parentheses indicate the deviation of the control location for that particular lever. The positive sign suggests that the location of the particular lever is to be increased further away from SRP whereas the negative sign indicates that the particular control is to be brought nearer to SRP in the same direction*

Table 7. Comparison of selected tractor workplace configurations with design values

Sl. No.	Control locations from SRP	Design value (T)	Tractor workplace location				
			TM_1	TM_2	TM_3	TM_4	TM_5
1.	Steering column angle, degree	65.0	50.0 (+15.0)	65.0 (0.0)	65.0 (0.0)	75.0 (-10.0)	64.0 (+1.0)
2.	Clutch pedal location, mm	875.0	720.0 (+155)	670.0 (+205)	740.0 (+135)	635.0 (+240)	600.0 (+275)
3.	Brake pedal location, mm	875.0	700.0 (+175)	660.0 (+215)	730.0 (+145)	600.0 (+275)	710.0 (+165)
4.	Draft control lever location, mm	287.0	330.0 (-43)	280.0 (+7)	285.0 (+2)	290.0 (-3)	396.0 (-109)

shifted by (+) 155 mm, (+) 205 mm, (+) 135 mm, (+) 240 mm, (+) 275 mm; brake pedal by (+) 175 mm, (+) 215 mm, (+) 145 mm, (+) 275 mm, (+) 165 mm; and draft control lever by (-) 43 mm, (+) 7 mm, (+) 2 mm, (-) 3 mm, and (-) 109 mm, respectively for the tractor configurations of TM_1, TM_2, TM_3, TM_4 and TM_5. It was observed that minimum shifting of controls was required in tractor TM_3, while major relocations of controls were required in TM_1, TM_2, TM_4 and TM_5 tractor models.

Foot controls like clutch pedal needed to be shifted by maximum of 275 mm for TM_5 model, and the brake pedal required to be shifted by maximum of 275 mm for TM_4 model. Kumar *et al*. (2009) had found that further horizontal forward movement of 180 mm was required to bring the foot controls into the workspace envelopes. They also concluded that this relocation placed the hand controls outside the workspace envelope. So, adjustment in seat location only cannot give the desired result of locating the controls within the workspace envelopes. Therefore, it is necessary to relocate the controls on the tractor so that they are placed within the workplace envelopes of the Indian population, and seat adjustment can only take care of anthropometric variability within that population.

The workplace dimensions of the selected tractors thus also varied from the design dimensions. This indicated that placement of tractor operator controls in the commercial models were ergonomically not appropriate for Indian tractor operators. Therefore, there is need to design a tractor operator workplace based on biomechanical and anthropometric data of the tractor operator population. In order to accommodate the 5^{th} to 95^{th} percentile tractor operators, provision for vertical and horizontal adjustment in seat is desirable.

CONCLUSIONS

Tractor workplace configurations with respect to the dimensions of steering column angle, position of hydraulic control lever, horizontal and vertical distance of clutch and brake pedal from SRP varied among five selected Indian tractor models. On comparison of their workplace configurations with the BIS IS 12343:1998; it was found that the steering column angle and lower horizontal distance of seat edge from SIP in all models, high (23^0) seat backrest inclination of the TM_5 model, lower seat backrest height in TM_4 and TM_5 model were the major variations. The location of controls on Indian tractors were located in areas designated by the BIS IS: 12343 standard in some tractors, but were not within the workspace envelopes for the Indian population resulting in mismatch. The selected tractor workplace configurations required changes in the steering column, brake pedal, clutch pedal, draft control lever to meet the design values based on anthropometric data of Indian operators. This might reduce the physical and mental stresses and improve comfort in operation. As the values of the tractor model TM_3 configuration were close to the design locations of controls, it could be concluded that the TM_3 model configuration was most suitable amongst the selected tractors.

ACKNOWLEDGEMENT

The authors are thankful to ASPEE Agricultural Research and Development Foundation, Malad (W), Mumbai, for providing financial assistance in the form of scholarship to conduct this research.

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Journal of Agricultural Engineering

Vol. 54 (4): October-December, 2017

Effect of Ohmic Heating on Quality and Recovery of Oil from Mustard Seed

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Article Info

Received : July, 2016
Revised
accepted : October, 2017

Key words: Mustard seed, ohmic heating, oil recovery, free fatty acids, colour value

ABSTRACT

The effects of process parameters on ohmic heating (electric field strength of 600 $V.m^{-1}$, 750 $V.m^{-1}$ and 900 $V.m^{-1}$), end point temperature (70 ºC, 80 ºC and 90 ºC) and holding time (5 min, 10 min and 15 min) were investigated on oil recovery from mustard seeds using laboratory model ohmic heating system. Primary quality attributes viz. free fatty acids and colour value of oil from ohmically treated mustard seeds was determined using standard methods. The maximum oil recovery (84.90 %) was obtained when the sample was heated at 90 ^oC using electric field strength of 750 $V.m^{-1}$ for a holding time of 15 min. The free fatty acid (1.11 % to 1.27 %) in the oil samples was within the acceptable limit (0.5-3.0 %). The L value of oil extracted from ohmic heated mustard seeds ranged from 40.32 to 40.87 as against 40.71 of control sample.

Mustard seed (*Brassica* Sp.), also known as rapeseed, is the second leading source of protein meal after soybean in the world (www.feedipedia.org). India is the third largest rapeseed oil producer in the world, after China and Canada, with 12 % of world's total production. Mustard seed is mainly used for oil extraction, besides used as an ingredient in pickles, meat and salad dressings and soups. Oil recovery from mustard seed ranges between 30-34 %, depending upon the quality of seeds. The oil remaining in the seed is recovered by solvent extraction process, which is uneconomical (Kalia *et al*., 2002). Moreover, residual solvent retention in oil and cake has potential health hazards. Oil recovery from oil seeds can also be increased by application of thermal pre-treatment such as dielectric, infrared and enhance diffusion by electroporation.

Ohmic heating is reported to produce uniform distribution in contrast to non-uniform distribution during microwave heating (Datta and Hu, 1992; Kim *et al*., 1996; Varghese *et al*., 2014). It also has an advantage over microwave processing, where processing can be limited by the depth to which energy can penetrate the food material (Fryer *et al*., 1993). Ohmic heating provides a considerable advantage for foodstuff applications by not only avoiding the degradation of thermo-sensitive compounds but also by reducing the fouling of treated food surfaces during processing (Ayadi *et al*., 2005). Ohmic heating is now receiving increased attention from the food industry. Applications of ohmic heating are in blanching, thawing, on-line detection of starch gelatinization, fermentation, peeling, evaporation, dehydration, fermentation and extraction (Sastry and Palaniappan, 1992; Castro *et al*., 2004; Pereira *et al*., 2007). Major benefits claimed for ohmic heating technology are continuous processing without heat transfer surfaces and uniform heating of liquids and carrier fluids at comparable rates, thus making it possible to use High Temperature Short Time (HTST) technique (Parrott, 1992; Tucker and Withers, 1994; Pereira *et al*., 2007).

Application of ohmic heating has been reported for various applications as in increasing in diffusion (Halden *et al*., 1990), extraction of fruit juices (Lima and Sastry, 1999; Wang and Sastry, 2000) and enhancement of drying process of sweet potato (Zhong and Lima, 2003), production of sucrose from sugar beet (Katrokha *et al*., 1984) and enhancement of production of soy milk from diffusion of soybean (Kim and Pyun, 1995). Lakkakula *et al*. (2004) reported that ohmic heating was an alternative method for stabilisation of rice bran, as it increased the oil yield of rice bran to a maximum of 92 % against only 53 % from the control samples. They conducted ohmic heating of rice bran samples weighing 10 g (21 % moisture content, wet basis) with a laboratory-scale ohmic heater equipped with titanium electrodes and using an alternating current of 1- 60 Hz and an electric field strength of 100 $V.cm^{-1}$. Loypimai *et al*. (2009) investigated the effect of ohmic heating on lipase activity, phytochemicals and antioxidant activity of rice bran obtained from different ohmic heating conditions. Brunton *et al*. (2005) reported that meat emulsion batters cooked very rapidly using ohmic heating. Rao *et al*. (2004) and Kumari *et al*. (2016) reported application of ohmic heating pre-treatment to rice bran and sesame seeds, and observed that use of ohmic heating resulted in higher oil recovery. Most of the research works were, however, confined to laboratory studies and are yet to be developed into technologies for higher oil yield at lower processing cost. The present study was thus undertaken to study the effect of ohmic heating on enhanced oil recovery from mustard seeds.

MATERIALS AND METHODS

Raw Material

Mustard seed (*var*. T-59) procured from local market was cleaned and graded using CIAE cleaner-cum-grader. The initial moisture content of raw mustard was determined by oven drying method (Rangnna, 2005). The oil content in raw mustard seeds was determined as per AACC (2000) using Soxhlet apparatus (Borosil Glassworks Ltd., Mumbai) and heating mantle (SUNBIM, Mumbai, India).

Experimental Design

Electric field strength (EFS), end point temperature (EPT) and holding time (HT) were considered as the independent variables; whereas temperature, electric current during ohmic heating, residual oil content in cake, free fatty acid in oil, peroxide value and colour of oil were considered as dependent variables. Two electrodes were fixed in geometric centre at two ends of the heating container with 0.16 m midline distance between electrodes to measure the end-point temperature. Three levels of EFS (600 $V.m^{-1}$, 750 $V.m^{-1}$, and 900 $V.m^{-1}$), EPT (70 °C, 80 °C, and 90 °C) and HT (5 min, 10 min, and 15 min) were used to investigate the effect of ohmic heating parameters on oil recovery from mustard seeds using full-factorial design (Pare *et al*., 2009).

Ohmic Heating of Mustard Seeds

A laboratory model of ohmic heating system (Fig. 1, 2) was developed for conducting experimental trials. It consisted of a heating chamber (L= 0.3 m, B = 0.2 m, H = 0.25 m) for holding oil seeds, SS electrodes for conducting current and control panel for monitoring the voltage, current and temperature. Preliminary trials on ohmic heating of mustard seeds at different moisture contents (20 %, 25 %, 30 % and 35 %)

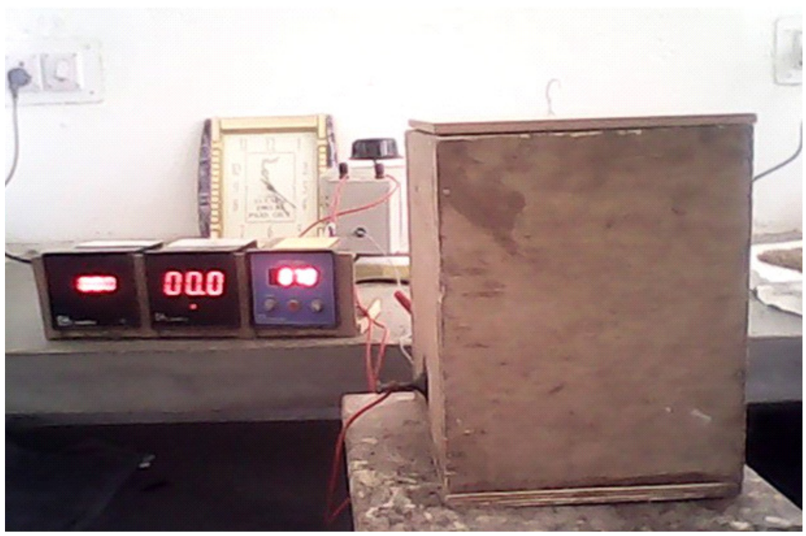

Fig. 1: Experimental setup for ohmic heating

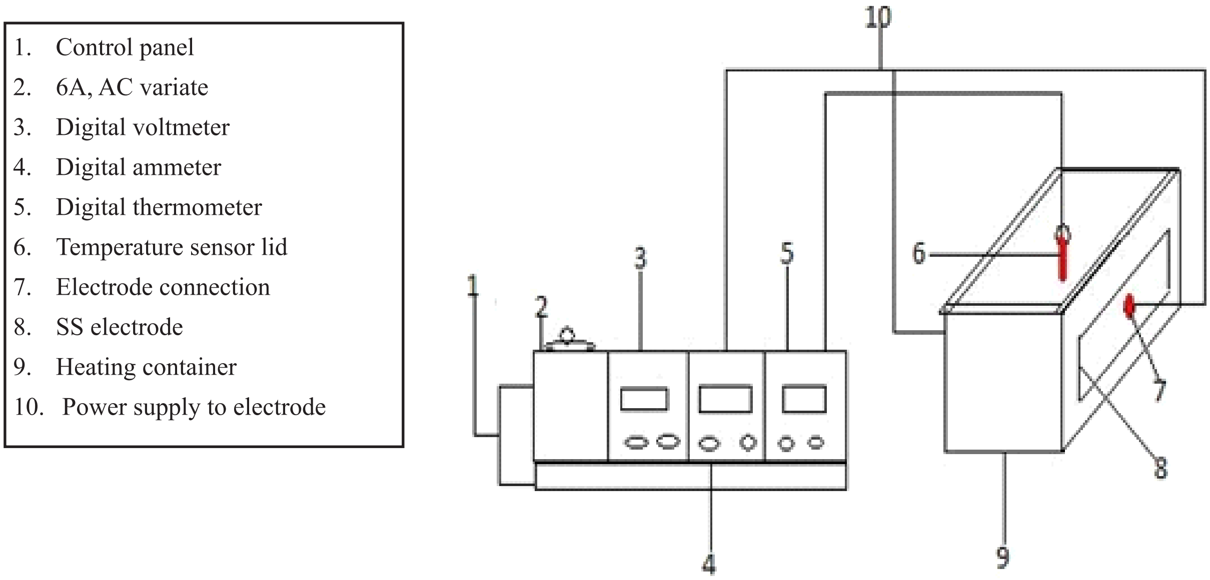

Fig. 2: Schematic diagram of experimental setup for ohmic heating

were conducted to standardise the moisture content that can attain end point temperature of 90 ºC. The moisture content of raw mustard seed was increased up to 30 % by adding the required amount of water (240 ml.kg^{-1}) as decided through preliminary experiment.

Experimental trials were conducted by placing 3.0 kg mustard seed sample into the heating container, and then applying required voltage to generate EFS of 600 V.m^{-1}, 750 V.m^{-1} and 900 V.m^{-1} with the help of an AC variate fixed on control panel until its geometric centre temperature reached the desired temperature (EPT) of 70 °C, 80 °C, and 90 °C. Seed samples were heated for the required hold time of 5 min, 10 min, and 15 min by keeping the sample at particular EFS and EPT. A PT-100 temperature sensor (0-200 °C) was placed into geometric centre of the sample to monitor temperature during heating. Current and temperature were recorded after every minute during ohmic heating. The required electric field strength was maintained with the help of a control panel. Uniform electric field was assumed since the electrodes were in excellent contact with the sample.

The ohmically treated sample was shade-dried to reduce the moisture content up to 10–12 % suggested for optimum oil expulsion by Shukla *et al*. (1992). Mustard seeds without any treatment were taken as control sample. A small capacity mechanical oil expeller (5 kg.h^{-1}) developed under TEPP programme of CTAE, MPUAT, Udaipur was used for oil expression of both ohmically treated and control samples. The residual oil content in oil cake was determined using a Soxhlet apparatus (AACC, 2000).

Quality Evaluation

Free fatty acid (FFA) is a primary quality attribute for edible grade oil. The PFA Act specify a maximum acceptable limit of FFA as 3 % while BIS specify a range of acceptable limit as 0.5-3.0 % (Ranganna, 2005). Free fatty acid (% oleic acid) present in the oil samples was determined by using the titration method (AOAC, 1990). The colour value of oil samples was determined by using Hunter Lab Colorimeter. (Model: CFLX/DIFF, CFLX-45; Manufacturer: Hunter Associates Laboratory, Virginia, USA; Illumination and viewing source: Dual beam Xenon flash lamp; Port / view diameters: 31.8 mm/25.4 mm).

Optimization of Process Parameters

Process parameters (EFS, EPT and HT) were optimized on the basis of the maximum oil recovery from mustard seeds, minimum FFA in oil and residual oil content in the cake. The optimization process was carried out using numerical optimization technique with the help of Design Expert 8.0.6 statistical software by response surface methodology (Madamba, 2002; Myers *et al.*, 2009).

RESULTS AND DISCUSSION

The initial moisture and oil content of mustard seed were determined as 6.25 % and 34.10 %, respectively.

Effect of Ohmic Heating on Oil Recovery

Oil recovery was found to increase with increase in end point temperature (EPT) and holding time for all electric field strengths applied (Table 1). Oil recovery increased with increase in electric field strength (EFS) from 600 V.m^{-1} to 750 V.m^{-1}, but decreased with further increase in EFS from 750 V.m^{-1} to 900 V.m^{-1}. Oil recovery from ohmic heated mustard seed was found to vary from 77.0 % to 84.9 per cent. Maximum oil recovery (84.9 %) was obtained from seed sample treated at 90 °C with omhic heating with electric field strength of 750 V.m^{-1} for a holding time of 15 min. The results are in agreement with the findings of Parrado *et al*. (2003), Lakkakula *et al*. (2004) and Tyagi *et al*. (2012) for rice bran. Similar results were also reported by Parascopic *et al*. (2006) and Kumari *et al*. (2016) for apples and sesame seeds, respectively. The ANOVA on oil recovery showed that the effect of all variables of the experiment (EFS, EPT and EPT) on oil recovery was highly significant (Table 2).

The combined effect of the two variables (keeping third variable at its central value) on per cent oil recovery is presented in Figs. 3-5. The figures clearly show that the oil recovery was highest at interactions of EFS and EPT. This increase in oil recovery might be the combined

Table 1. Oil recovery from ohmic heatedmustard seed and quality attributes of oil

EFS, V.m^{-1}	EPT, ºC	HT, min	Oilre-covery, %	Residual oil content, %	FFA, % oleic acid	L*	a*	b*
		5	77.16	11.80	1.2690	40.48	9.92	30.42
	70	10	77.78	11.48	1.2661	40.35	10.56	29.51
		15	80.41	10.12	1.2718	40.71	11.63	32.42
		5	80.47	10.08	1.2267	40.44	11.63	30.49
OH600V	80	10	80.83	9.96	1.2323	40.44	11.06	31.56
		15	81.36	9.63	1.2295	40.70	10.66	31.61
		5	83.54	8.50	1.1674	40.50	11.44	30.15
	90	10	83.81	8.36	1.1590	40.33	12.01	32.48
		15	84.32	8.08	1.1646	40.32	11.99	30.22
		5	79.71	10.48	1.2379	40.66	10.44	31.55
	70	10	80.85	9.89	1.2323	40.54	11.55	31.88
		15	81.78	9.41	1.2379	40.35	11.66	32.41
		5	82.67	8.95	1.1449	40.39	10.59	31.66
OH750V	80	10	82.85	8.86	1.1562	40.45	10.86	31.54
		15	83.78	8.38	1.1505	40.73	10.47	31.18
		5	83.95	8.29	1.1054	40.60	10.65	31.58
	90	10	84.20	8.16	1.1054	40.66	10.86	31.63
		15	84.90	7.8	1.1167	40.75	10.54	31.54
		5	77.00	11.88	1.1928	40.66	10.88	31.59
	70	10	77.80	11.47	1.1872	40.32	10.91	31.44
		15	79.67	10.5	1.1985	40.56	10.44	31.8
		5	80.12	10.27	1.1787	40.44	11.36	32.47
OH950V	80	10	80.66	9.99	1.1759	40.87	11.91	32.86
		15	82.92	8.82	1.1731	40.82	11.54	32.48
		5	83.21	8.67	1.1787	40.63	12.01	32.44
	90	10	83.64	8.45	1.1731	40.87	12	32.74
		15	83.85	8.34	1.1712	40.55	11.68	31.91
Control sample			73.75	13.56	1.027	40.71		

Note: *EFS - Electric field strength, EPT - End point temperature, HT - Holding time, FFA - Free fatty acid*

Table 2. Analysis of variance (ANOVA) of oil extraction from ohmically heated mustard seed

Source of variance	DF	SS	MS	Fcal.	SE(m)	CD (1%)	CV
Oil recovery							
Electric field strength	2	98.0229	49.0114	976.828**	0.043	0.163	2.11
End point temperature	2	574.1180	287.0590	5721.264**	0.043	0.163	
Holding time	2	74.6265	37.3133	743.676	0.043	0.163	
Error	54	2.7094					
Residual oil in cake							
Electric field strength	2	14.2044	7.1022	1005.381**	0.016	0.046	0.88
End point temperature	2	83.6319	41.8159	5919.418**	0.016	0.046	
Holding time	2	10.8200	5.4099	765.831**	0.016	0.046	
Error	54	0.3814					
FFA (% oleic acid)							
Electric field strength	2	0.0440	0.0220	8.402**	0.010	0.028	
End point temperature	2	0.0948	0.0474	18.062**	0.010	0.028	0.84
Holding time	2	0.0001	5.78e-005	0.022	0.010	0.028	
Error	54	0.1417					
Colour (L*) value							
Electric field strength	2	0.3617	0.1808	2.151	0.056	0.158	0.71
End point temperature	2	0.0822	0.0411	0.489	0.056	0.158	
Holding time	2	0.1074	0.0537	0.639	0.056	0.158	
Error	54	4.5403					

**, ** Significant at 5 % and 1 %, respectively.*
DF: Degree of freedom, SS: Sum of squares, MS: Mean of squares, CV: Critical value

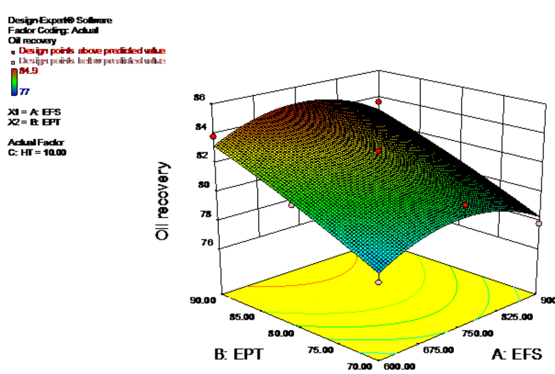

Fig. 3: Effect of ETP and EFS on oil recovery

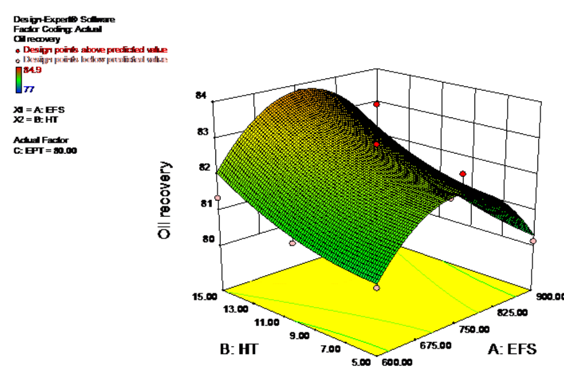

Fig. 4: Effect of holding time and EFS on oil recovery

effect of electroporation of cell membranes and thermal softening of the tissues as explained by Praporscic *et al*. (2006) for juice yield from potato and apple.

Effect on Residual Oil in Cake

The residual oil content in cake ranged from 7.8 % to 11.8 % (Table 1). The minimum residual (7.8 %) corresponded to the conditions of maximum oil recovery at EFS of 750 V/m, EPT 90 °C, and holding time of 15 min. The results justified the usefulness of ohmic heating treatment, as residual oil of 8–14 % in the mustard cake from oil expellers has been reported

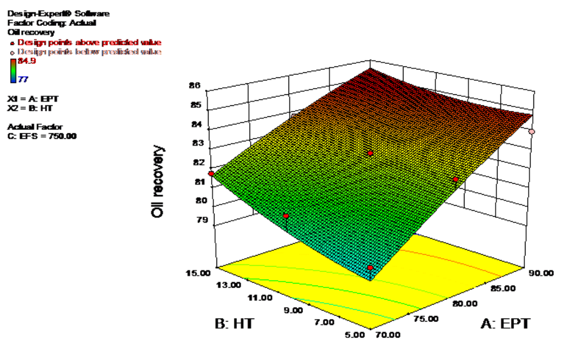

Fig. 5: Effect of holding time and EPT on oil recovery

by Srikantha (1980) and Singh and Singh (2013). The ANOVA of residual oil content in mustard seed indicated that the parameters EFS, EPT and HT had significant effect at 1 % level (Table 2).

Effect of Ohmic Treatment on Quality of Extracted Oil

Primary quality attributes (free fatty acid, colour value) of oil samples extracted by ohmical treatment were evaluated, and the effect of EPT, EFS and holding time is presented.

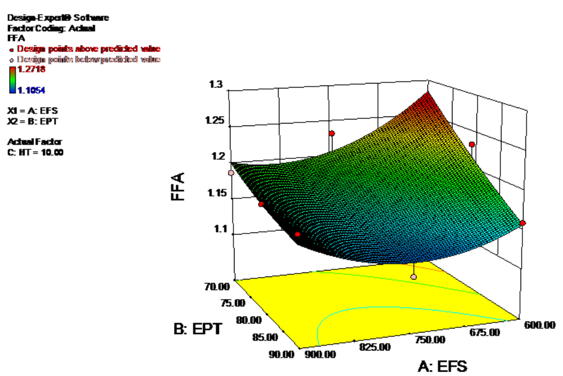

Fig. 6: Effect of EPT and EFS on FFA of oil

Free fatty acids

The effects of EPT and EFS on FFA content of oil samples are shown in Fig. 6. FFA value of oil recovered from ohmically heated mustard seed samples was in the range of 1.11 % to 1.27 % as against 1.03 % in the control sample, and was within the acceptable limit of 3.0 % (Table 1). Similar results were reported by Nagre *et a*l. (2011) for Kombo kernel and Kumari *et al*. (2016) for sesame seeds. ANOVA of FFA (Table 2) shows that the effect of EFS and EPT were highly significant at 1 % level, while the effect of holding time was non-significant. The increase in FFA value with increase in temperature might be due to hydrolysis which occurred in the oil, and might have been caused by water and lipase enzymes (Soetaredjo *et al*., 2008; Orhevba *et al*., 2013). Akubugwo and Ugbogu (2007) had reported that during extraction process, water inside the seed bed flows out along with the oil and reacts with triglycerides to form free fatty acids and glycerols.

Colour value

The L* value of ohmically heated oil samples was in the range of 40.32 to 40.87 as against 40.71 of the control sample. The results were in confirmation with the findings of previous research (Torres and Maestri, 2006). ANOVA for colour value of the oil samples shows that the effect of EFS, EPT and HT was non-significant (Table 2). No significant difference was observed in colour values (a*, b*) of all oil samples of mustard seeds when compared with the control sample oil. Standard deviation of a* and b* colour values of extracted oil of all 27 sample, when compared from a* and b* colour values of the control sample was 0.847 and 0.858, respectively.

Optimization of Process Parameters

The desired goals of each factor and response are shown in Table 3. Equal importance '3' was given to

Table 3. Process variables and response for ohmic heating

Attribute	Goal	Lower limit	Upper limit	Importance	Optimum Value
EFS, $V.m^{-1}$	Minimize	600	900	3	695.49
EPT, °C	Minimize	70	90	3	82.73
HT, min	Minimize	5	15	3	5.00
FFA, %	Minimize	1.11	1.27	3	1.16
Residual oil, %	Minimize	7.80	11.88	3	8.91
Oil recovery, %	Maximize	77.00	84.90	3	82.75

the process parameters, and responses to maximize the desirability function by numerical optimization. The optimum value of oil recovery, residual oil content in cake and FFA in extracted oil were found to be 82.75 %, 8.91 %, and 1.16 %, respectively for a combination of ohmic heating parameters (695.49 $V.m^{-1}$ EFS, 82.73°C EPT and 5 min HT) as generated by numerical optimization. These generated values of ohmic heating parameters were more or less same as shown in Table 1. Maximum oil recovery and minimum residual oil content in the cake was obtained when the sample was ohmically heated by 750 $V.m^{-1}$ at 90 °C for 15 min, but the minimum FFA was recorded at 750 $V.m^{-1}$ at 90 °C for 5 min HT. The results were in agreement with the finding of Kumari *et al*. (2016),who studied the effect of ohmic heating on sesame oil and reported that the optimum values of ohmic heating parameters for maximum oil recovery, minimum residual oil content, free fatty acid (FFA) and peroxide value were 722.52 $V.m^{-1}$ EFS at EPT 65°C for 5 min holding time.

CONCLUSIONS

Maximum mustard oil recovery of 84.9 % (15.11 % higher than from sample without treatment) was obtained from omhically treated seed at 90°C with electric field strength of 750 $V.m^{-1}$ for a holding time of 15 min. The effect of EFS, EPT and EPT was significant on oil recovery, residual oil content in cake and FFA value; but was non-significant for colour value of oil. This FFA value of oil was safe and below the maximum permissible limit (3 %) at all combinations of treatment. The optimum value of oil recovery, residual oil content and FFA as generated by numerical optimization were 82.75 %, 8.91 %, and 1.16 %, respectively, for ohmic heating EFS (695.49 $V.m^{-1}$), EPT (82.73°C) and HT (5 min).

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Journal of Agricultural Engineering

Vol. 54 (4): October-December, 2017

Characterization of Attributes in Dehusked Coconut

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Article Info

Received : April, 2017
Revised
accepted : November, 2017

Key words: Dehusked coconut, physical properties, correlation and frequency distribution

ABSTRACT

Selected physical properties of dehusked coconut as length, width, thickness, geometric mean diameter, sphericity, surface area, bulk density and true density were investigated. Compositional changes in coconut fruits, including volume and weight, shell weight, weight of mature coconut water, wet and dry flesh weight, thickness of the flesh and shell were also evaluated. The average fruit length, major diameter and minor diameter were 99.2±13.3 mm, 91.5±8.9 mm, and 89.5±8.7 mm, respectively; while the sphericity, true density, bulk density and surface area were 0.90±0.05, 998±68.8 kg.m^{-3}, 483±37.3 kg.m^{-3} and 274.2±50.4 cm^{2}, respectively. The frequency distribution of the major diameter and the fruit mass followed the Gaussian model. Correlations between fruit characteristics were also determined. Results indicated that fruit weight and total wet flesh weight were closely correlated, and both of these characteristics can be used as an indicator of fruit size.

Cocos nucifera is the scientific name of the common coconut which is a Spanish word, *coco* meaning "head" or "skull" from the three indentations on the coconut shell that resemble facial features, and *Nucifera* means "nut-bearing". Coconut provides a nutritious source of meat, juice, milk, and oil that has fed and nourished populations around the world for generations. Among these cultures, coconut has a long and respected history. Coconut is highly nutritious and rich in fibre, vitamins, and minerals. It is classified as a "functional food" as it provides many health benefits beyond its nutritional content. Coconut oil is of special interest, because it possesses healing properties far beyond that of any other dietary oil and is extensively used in traditional medicines among Asian and Pacific populations. Pacific islanders consider coconut oil to be the cure for all illness. Coconut palm is highly valued by them as both a source of food and medicine that it is called "The Tree of Life" (Laura, 2016).

The fruit structurally comprises of a green skin, a fibrous husk, and a shell that encloses the flesh and juice. The appearance of coconut fruit changes from the time of pollination and with increasing age. Each bunch of 10 or more fruits in the tree represents an age of about one month. Within a month of pollination, small buds develop. With increasing age, the fruits increase in size and can be seen to be radially located around the tree trunk downward in clockwise fashion, the oldest bunch being in the lowest layer. A bunch 6-7 months old represents as mucous-like meat, 7-8 months old as cooked rice-like meat and 8-9 months as leather like meat (Rosario and Malijan, 1989).

Physical specifications of agricultural products constitute the important parameters needed in the design of grading, transfer, processing, and packaging systems (Kashaninejad *et al*., 2006; Sirisomboon *et al*., 2007). The size of fruit determines its market value, and is also important for designing the sizing machine as also to determine the lower size limit of the conveyor such as belt conveyor, bucket elevator and screw conveyor. The product shape can be determined in terms of its sphericity and aspect ratio, which affect the flowability characteristics of the products (Madhusudan *et al*., 2016). Surface area affects the resistance to airflow through a bulk material bed, and data on them are necessary in designing a drying process. Bulk density is used in determining the size of the storage bin (Sirisomboon *et al*., 2007).

Jahromi *et al*. (2008) evaluated the linear dimensions, geometric mean diameter, sphericity and surface area of date fruit. The major axis has been found to be useful by indicating the natural rest position of the fruit. Shidenur *et al*. (2017) determined the length and diameter of jackfruit by image processing technique. The mean length and diameter of the fruit were found to be 380±70.79 mm and 220.67±20.55 mm, respectively. They reported that these dimensions can be used in designing machine components. Sirisomboon *et al*. (2007) reported physical properties of *Jatropha curcas L.* fruits, nuts and kernels. The sphericity values indicated that the fruit shape (0.95) is close to a sphere compared to the nut (0.64) and kernel (0.68). Topuz *et al.* (2005) studied the physical and nutritional properties of four varieties of orange. They presented their report on dimensions, volume, mean geometrical diameter, surface area, fruit density, porosity, packaging coefficient, and friction coefficient. Studies on physical properties of special fruits such as gumbo can be found in the literature (Akar and Aydin, 2005).

The aim of this study was to investigate the post-harvest physical properties of dehusked coconut. The parameters investigated include length, width and thickness, geometric mean diameter, sphericity, bulk density and true density, fruit volume and weight, wet and dry flesh weight, shell weight, thickness of the flesh and shell.

MATERIALS AND METHODS

Plant Material

Coconuts of variety West Coast tall were obtained from Sungaramudaku village, near Pollachi, Coimbatore, Tamil Nadu. It was harvested from trees bearing 12-13 months old fruits, which was identified and harvested with the help of well experienced farmers. The fruit contained the nut enclosed by the husk of fibrous layers. The outer husk was removed. In order to determine the frequency distribution and properties of coconut, randomly 100 nuts were selected. Four size grades of>110 mm (first grade), 101-110 mm(second grade) , 91-100 mm (third grade) and 80 – 90 mm (fourth grade) were chosen and 50 of each grades, totalling to 200 nuts were selected to study the analysis of variance between the grades of dehusked coconut. SPSS-15 software was used for the analyses.

Fruit Characteristics

Three principle dimensions, namely length, major diameter (width) and minor diameter (thickness) of each fruit were measured using a digital vernier caliper, which had an accuracy of 0.05 mm. The width and thickness are perpendicular to each other. To obtain the mass, each fruit was weighed (w_1) with an electronic balance of 0.01 g accuracy.

Fruits were carefully opened to avoid damage to the flesh and the shell. The coconut water was drained off, and the weight was measured (w_2). By subtracting w_1 and w_2, the amount of coconut water present in each fruit was measured. The wet flesh of coconut was sun dried to determine the dry flesh weight (w_4). In sun drying, the cups were spread over an open surface in a single layer directly facing the sun. During non-sunshine periods and nights, the cups were covered with a polyethylene sheet to avoid desorption of moisture. After second day, the cups were manually removed from the shells and dried for another five days to obtain constant weight of 8 % moisture content (w.b.). The weight of the shell of each fruit was measured (w_3). Wet flesh weight (w_5) was calculated by subtracting w_2 and w_3. Thickness of the shell was determined using a screw gauge. The percentage shell weight, wet and dry flesh weight was calculated using w_3/w_1, w_5/w1 and w_4/w_1, respectively.

Geometric mean diameter, sphericity, surface area

Geometric mean diameter (D_g), sphericity (Φ), and surface area (S) were calculated by using the following equations (Jahromi *et al*., 2008):

$$D_g = (LWT)^{1/3} \quad (1)$$

$$\Phi = D_g/L \quad (2)$$

$$S = \pi D_g^{\,2} \quad (3)$$

Where,

L = Length of dehusked coconut, mm,

W = Width of dehusked coconut, mm, and

T = Thickness of dehusked coconut, mm.

True density

True density of dehusked coconut was determined by water displacement method (Sahay and Singh, 1986) in a graduated cylinder. In case a fruit floated, the fruit was gently submerged with the help of a 2 mm diameter glass rod.

$$True\ volume = \frac{Mass\ of\ displaced\ water\ \ (kg)}{Density\ of\ water\ (kg.m^{-3})}$$ …(4)

By knowing the mass of the dehusked coconut in air and the true volume, the true density was obtained as the ratio between the mass of dehusked coconut in air to its true volume.

$$\rho_t = \frac{W_a}{V_a}$$ ...(5)

Where,

ρ_t = True density of dehusked coconut, kg.m^{-3},

W_a = Mass of dehusked coconut in air, kg, and

V_a = True volume of dehusked coconut, m^3.

Bulk density was determined using the mass volume relationship (Sahay and Singh, 1986) by filling an empty container of predetermined volume and weight. Dehusked coconuts were poured from a constant height, striking off the top level and weighed. Bulk density was calculated as the ratio between mass and bulk volume of container expressed as kg.m^{-3}.

Coefficient of friction

The experimental apparatus used for the friction studies was similar to that reported by Kaleemullah and Kailappan (2003) for chillies. The apparatus consisted of a frictionless pulley fitted on a frame, a cylinder (150 mm x 190 mm) open on both sides, loading pan and test surfaces. The cylinder was connected by means of a string, parallel to the surface of the material and passed over a frictionless pulley with a pan hanging from it. The cylinder placed on the test surface was kept full with a dehusked coconut, and weights were added to the loading pan until the cylinder began to slide. The mass of dehusked coconut and the added weight represented the normal force and frictional force, respectively. The co-efficient of static friction was calculated as the ratio of frictional force to the normal force as,

$$\mu = \frac{F}{N_f}$$ …(6)

Where,

μ = Co-efficient of friction,

F = Frictional force, kg, and

N_f = Normal force, kg.

The experiment was performed using test surfaces of cardboard, galvanized iron, aluminium, and stainless steel sheets. Experiments were replicated three times by emptying and refilling with different samples in the container and the average value was reported.

RESULTS AND DISCUSSION

Physical Properties

Major diameter and weight

The frequency distribution of major diameter (width) and the weight of nut are shown in Fig. 1(a) and Fig. 1(b) for 100 samples. The minimum and the maximum major diameter of dehusked coconut were found to be 70 mm and 120 mm, respectively. The frequency of major diameter at the range of 90 mm to 100 mm was highest. The minimum and maximum weights of nut were 180g and 725g, respectively. Maximum number of nuts had their individual weights in the range of 400 to 600 g. The shape of the curves of major diameter and weight of nut showed a normal distribution and followed Gaussian model.

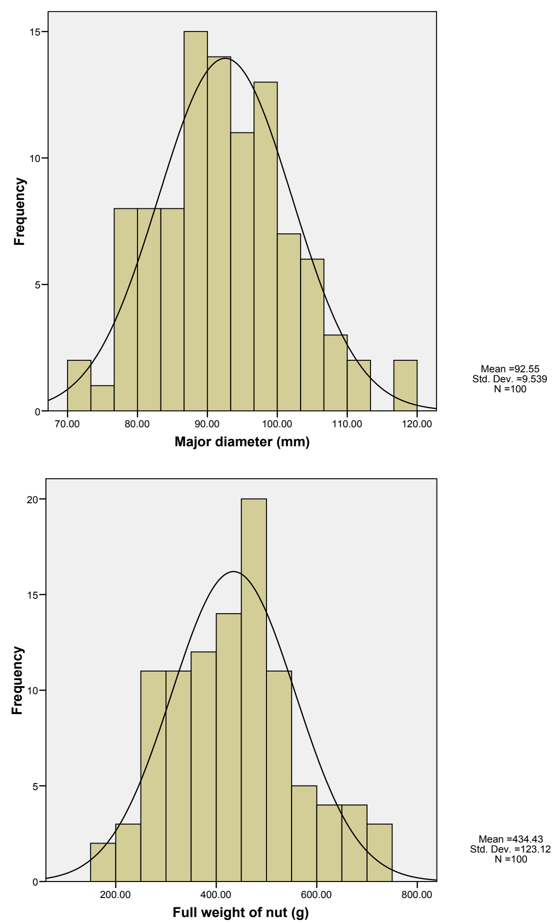

Fig. 1: Frequency distribution of fruit size dimensions of 150 dehusked coconut at harvest -(A) Major diameter; (B) Fruit mass

Fruits exhibited a wide range of sizes with the length, width and thickness. These dimensions might be useful in estimating the size of machine components. Width of dehusked coconut was found to be 91.5±8.9 mm (Table 1).

Sphericity, density, surface area

The mean sphericity was found to be 0.90, and indicative of the tendency of the shape towards a sphere. True density, bulk density and surface area of dehusked coconut were 998 kg.m^{-3}, 483 kg.m^{-3}, and 274.2 cm^{2}, respectively. These properties might be useful in separation and transportation of the dehusked coconut. The importance of these and other characteristic as axial dimensions in determining aperture size of machines, particularly in separation of materials have been discussed by Omobuwajo *et al.* (1999) for African breadfruit seeds.

Table 1. Size parameters of dehusked coconut

Property	Mean ± SD	Number of observations
Length, mm	99.2 ± 13.3	100
Major diameter, mm	92.5 ± 9.5	100
Minor diameter, mm	89.5 ± 8.7	100
Geometric mean diameter, mm	92.9 ± 9.7	100
Sphericity	0.90±0.05	100
Surface area, cm^{2}	274.2 ± 50.4	100
Bulk density, kg.m^{-3}	483 ± 37.3	25
True density, kg.m^{-3}	998 ± 68.8	25

Range of property values

The properties of dehusked coconut fruit showing mean, minimum, maximum values and standard deviation obtained in this study are listed in Table 2. Fruits ranged widely in weight with these characteristics exhibiting 4.1-fold increase between the smallest and largest fruits. Fruits encompassed the full range of commercial grading classes. Fruit volume ranged between 714 cm^{3} to 281 cm^{3} exhibiting 2.6-fold increases between the smallest and the largest fruits. Fruit maturity could impact fruit size, and fruit size could also vary with the genotype (Hazel *et al*., 2011).

Total wet flesh weight, shell weight, shell thickness and dry flesh weight per fruit exhibited 3.1-, 2.7- , 2.6- and 3.2- fold difference respectively, among all the fruit sampled. The percent of wet flesh weight, dry flesh weight and shell weight exhibited 1.4-, 2.2- and 2-fold differences, respectively. Notable is that the percent wet flesh weight was relatively consistent, and varied up to 1.4 times difference among the fruits of all sizes.

Frictional properties

Table 3 shows the calculated coefficient of friction of dehusked coconut on cardboard, rubber, stainless steel, aluminium, and galvanised iron surfaces. Higher coefficient of friction was on rubber (0.43), followed by galvanised iron sheet (0.388), showing that these surfaces exerted more friction on dehusked coconut. Lower friction was experienced on aluminium (0.256). The behaviour was also due to the properties of friction surfaces (Ozguven and Vursavus, 2005). Similar results were observed by Zhiguo *et al.*(2011) for tomato fruit.

Table 2. Characteristics of dehusked coconut[a]

Parameter	Mean	Maximum	Minimum	Standard deviation
Total fruit weight, g	434.43	726	174	123.12
Fruit volume, cm^{3}	505.26	714	281	147.49
Wet fresh weight, g	225.26	348	110	53.42
Shell weight, g	118.83	173	64	26.16
Thickness of shell, mm	3.79	6.5	2.44	0.70
Thickness of flesh, mm	11.67	14.10	9.01	1.08
Dry flesh weight, g	125.10	201	62	28.65
Weight of water, g	86.38	249	2	50.38
% of fresh kernel weight to total weight of nut	53.18	63.22	44.61	4.55
% of dry flesh weight to total weight of nut	29.82	40.51	18.18	4.49
% of shell to total weight of nut	28.25	38.15	18.46	3.51

[a]*Data are for 100 fruits*

Fruit Character Correlation

The correlation matrix relating the different dehusked coconut fruit characteristics is presented in Table 4. Fruit characteristics as major diameter, full nut weight, shell weight, weight of mature coconut water and wet flesh weight were strongly correlated withfruit weight and total fresh kernel weight

Full weight of nut and major diameter indicated strong positive relationships with wet flesh weight ($r = 0.96$ and 0.91, respectively), indicating that larger fruit were heavier and had greater total fresh kernel weight (significant at 0.05 level). Shell weight was highly correlated with full weight of nut. Weight of mature coconut water also showed strong positive association with full weight of nut. In contrast, the fruit length was poorly correlated with the weight of copra, shell weight, shell thickness, weight of mature coconut water and wet flesh weight. Likewise, the shell thickness was also poorly correlated with all fruit characteristics, indicating that heavier and bigger coconut were not influenced by shell thickness. Similar results were obtained by Hazel *et al*. (2011) for pomegranate fruit characteristic correlation matrix.

Table 3. Coefficient of friction of dehusked coconut

Surface	Mean ±SD
Card board	0.272 ± 0.07
Rubber	0.430 ± 0.09
Stainless steel	0.318 ± 0.07
Aluminium	0.256 ± 0.06
Galvanised iron sheet	0.388 ± 0.11

Fruit Grade Attributes

Means of length, major, minor, mass, wet flesh weight, shell weight, dry flesh weight and shell thickness of the four grades of dehusked coconut were compared, Table 5. Analysis of variance revealed that there was significant difference in length, major diameter, minor diameter, mass, wet flesh weight, shell weight and dry flesh weight among the four grades of dehusked coconut [>110 mm (first grade), 101-110 mm (second grade), 91-100 mm (third grade), 80 – 90 mm (fourth grade)] at 1 % level of significance. Similar results were reported by Sharifi *et al*. (2007) for physical properties of orange (var. Tompson).

CONCLUSIONS

Understanding fruit attributes is essential, as market rewards for large-sized fruits and producer targets high total wet flesh weight. Therefore, the present study mainly focused on fruit attributes in West coast tall dehusked coconuts.

Dehusked coconut total fruit weight ranged from 174 g to 726 g, and fruit volume varied from 281 cm^3 to 714 cm^3. Percent of wet flesh weight, dry flesh weight and shell weight exhibited 1.4-, 2.2- and 2-fold differences, respectively. Highest coefficient of friction

Table 4. Correlation between the properties of dehusked coconut

	Length, mm	Major diameter, mm	Minor diameter, mm	Full weight of nut, g	Shell weight, g	Dry flesh weight, g	Shell thickness, mm	Weight of mature coconut water, g	Wet flesh weight, g
Length, mm	1								
Major diameter, mm	0.2832	1							
Minor diameter, mm	0.3072	**0.9838**	1						
Full weight of nut, g	0.4015	**0.9179**	**0.9189**	1					
Shell weight, g	0.4218	0.7897	0.7901	**0.8719**	1				
Dry flesh weight, g	0.3903	0.7020	0.7091	0.8219	0.8111	1			
Shell thickness, mm	-0.0750	0.2744	0.2735	0.2616	0.2830	0.2704	1		
Weight of mature coconut water, g	0.3431	0.8247	0.8255	**0.9282**	0.6860	0.6788	0.1483	1	
Wet flesh weight, g	0.3807	**0.9176**	**0.9191**	**0.9661**	**0.8411**	**0.8270**	0.3150	**0.8266**	1

Table 5. Analysis of variance as related to graded dehusked coconut physical properties

Dependent variable	Source	Sum of squares	Mean squares	F
Length		2165.704	721.901	14.168*
	Error	10801.951	50.953	
	Total	12967.656		
Major diameter		21771.408	7257.136	971.874*
	Error	1583.037	7.467	
	Total	23354.444		
Minor diameter		20476.291	6825.430	673.299*
	Error	2149.105	10.137	
	Total	22625.396		
Mass		54.4×10^5	18.1×10^5	474.180*
	Error	81.1×10^4	3827.305	
	Total	62.5×10^5		
Wet flesh weight		33.1×10^4	11.0 x 104	140.892*
	Error	16.6×10^4	785.414	
	Total	49.8×10^4		
Shell weight		20.8×10^4	69.5 x 103	165.664*
	Error	89.0×10^3	419.876	
	Total	29.7×10^4		
Dry flesh weight		16.8×10^4	56.0 x 103	100.937*
	Error	11.7×10^4	554.879	
	Total	28.5×10^4		
Shell thickness		3.893	1.298	3.740**
	Error	73.552	.347	
	Total	77.445		

**Significant at 1% level **Significant at 5% level*

was offered by rubber surface, followed by galvanised iron sheet and stainless steel sheet. Values of these parameters would be useful in designing of handling and processing equipment.

ACKNOWLEDGEMENT

The authors acknowledge University Grants Commission, Government of India, for funding this work.

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Journal of Agricultural Engineering

Vol. 54 (4): October-December, 2017

Development of Motorized Walnut Dehuller

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Article Info

Received : May, 2016
Revised
accepted : October, 2017

Key words: Walnut dehuller, heaping days, peripheral speed,effective throughput capacity, hulling efficiency

ABSTRACT

Most of walnut production is manually hulled in India. Green walnut is processed in dry condition by removing the outer shell. Removing of outer shell of walnut with a knife by hand is difficult at a low production rate of 0.025- 0.030 $t.h^{-1}$. A motorized walnut dehuller based on the principle of shearing-off the hull of a green walnut by shearing force was developed and evaluated, with peripheral speed and number of heaping days being optimized to make the best quality of hulling process. Results indicated that the effective throughput capacity, hulling efficiency and fully hulled walnut percentage increased with increase in peripheral speed. Similarly, hulling efficiency increased with increase in number of heaping days before hulling, but the fruit shell staining and kernel discoloration took place with increase in the number of heaping days after harvest. At peripheral speed of 6.41 $m.s^{-1}$ and 4-day heaping period, the hulling capacity of the developed machine was 0.260 $t.h^{-1}$ with hulling efficiency of 79.55 per cent.

Jammu and Kashmir is a major walnut producing state of India, and is famous throughout the world for its outstanding quality. Walnut is the second major horticultural cash crop of the state after apple. The area under walnut cultivation in Kashmir valley alone was 51,021 ha, and covered 87.9 % of total area under dry fruits, with production of 1,74,053 MT. The foreign exchange earnings from dry fruits have reached up to ₹ 6000 crores in 2015-16 (Dar, 2017). The area under walnut has continuously increased in Jammu and Kashmir. It was 59,900 ha in 2000-01, and increased to 89,339 ha in 2016-17, reflecting an increase of 49.1 % (Dar, 2017). Production has also increased from 83,399 MT in 2000-01 to 2, 66,280 MT in 2016-17. (Dar, 2017).

Dehulling (removal of green hull from the walnut after harvest) is an important postharvest operation in walnut processing that has considerable effect on the quality, chemical and microbial properties of walnuts. Removing the green hull and drying are two important postharvest processing operations. The presence of tannins in the hull of walnuts, which are readily formed on exposure to air, cause shell blackening and hastens the change in kernel colour from white to yellow or light brown (Chegini and Makarichian, 2015). The stain also discolours the human skin, clothing, or anything else that it touches.

Traditionally green walnut is kept under rice/mustard straw or under polythene sheets in the form of a heap for 5-6 days. Green hull becomes spongy, making it easy for its removal from the walnuts. For fast hull loosening, sometimes heaps are drenched with water once or twice a day. In this traditional process of heaping, the hull decay and consequent shell staining and kernel discoloration are common features due to heat generation and ingress of moisture and Juglone (5-hydroxy-1, 4-naphthalenedione) inside the walnuts. The hull decay can be minimised if the holding period of green walnuts in the heap is shortened. Walnut pericarp is then broken by beating with hammer/ stick or by using a sharp knife, and the green hull is separated (Fig. 1). The process of manual removing of green hull from the walnut is very tedious, laborious and time consuming, resulting in deterioration of the quality of un-shelled walnut. Harvested walnuts have a relatively high (32.9 % w.b.) moisture content, while a moisture content of 8% is needed for storage (Thompson and Grant, 1992; Rajabipour *et al*., 2010). Traditional methods of walnut hulling are thus not sufficient to handle the market demand. No suitable

Fig. 1: Traditional method of walnut dehulling using knife

machine or technology is presently available for the dehulling of walnuts in India. Walnut dehullers locally developed are generally based on shearing principle. Chinese walnut dehuller uses high-speed blade to cut the green shell of walnut, and walnut freely roll over while cutting making each surface properly cut. The residual shells are cleaned with the help of wire brush, and clean walnuts get out of the processing area into a container. The throughput capacities of such machines have been reported as 5-20 $t.day^{-1}$ with hulling efficiency of 99 % (Anon., 2017). However detail literature is not available on walnut dehulling. Therefore, a mechanized dehulling machine is required to save time, energy and to maintain quality of produce. Keeping in view the above facts, a motorized walnut dehulling machine suitable for on-farm use of small farmers was designed, developed and evaluated.

MATERIALS AND METHODS

The present research work was undertaken at the Division of Agricultural Engineering, SKUAST-K, Srinagar, India. Before development of the prototype, the required physical and engineering properties of walnut were determined in the Process and Food Engineering Laboratory of Division of Agricultural Engineering, SKUAST-K Shalimar and Structural Laboratory of Civil Engineering Department of National Institute of Technology, Srinagar, Kashmir.

Determination of Physical Characteristics of Walnut

The length (L), width (W), and thickness (T) of green walnut were determined. A sample of 100 green walnuts from seedling plantations was randomly selected from farmers' fields in Nishat, Srinagar, during September, 2014, and the required dimensions were measured using Mitutoyo digital Vernier callipers having least count of 0.02 mm . Each dimension was measured with 10 replications, and their mean was determined. Sphericity was determined by calculating the geometrical diameter. The equivalent diameter (D_g) as the geometrical mean of the three dimensions was calculated using the following expression:

$$D_g = (LWT)^{1/3} \quad \dots (1)$$

Sphericity was computed (Mohsenin, 1986) as:

$$Ø = (D_g/L) \times 100 \quad \dots (2)$$

Where,

Ø = Sphericity,

D_g = Equivalent diameter, mm, and

L= length of walnut, mm.

Construction of Dehulling Machine

Before construction of the machine, a conceptual view of machine was made using AUTO CAD-2010. Based on conceptual views, the machine was developed with objectives of minimization of mechanical losses, operational safety and minimization of efforts of the workers in hulling of walnut.

Constructional details

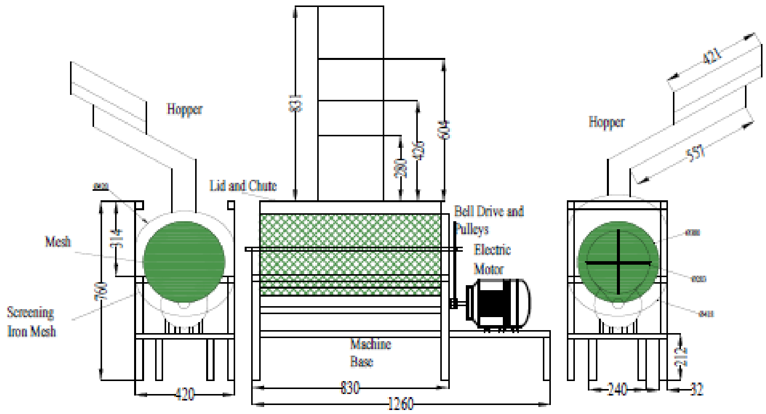
The main components of the dehuller are a frame, a hopper, a dehulling unit, an outlet chute and an electric motor (Fig. 2). The power for the machine was provided by a 0.75 kW single-phase electric motor. The power from the motor was transmitted to the dehulling unit through a belt-and-pulley drive.

Frame

A frame of size 1260 x 890 x 1630 mm was fabricated using mild steel angle (50x 50 mm) to support all components of the machine. The frame was strong enough to bear the transmitted load during the operation of dehulling unit.

Hopper

A trough and tube shaped hopper of 421 mm length, 290 mm width and 460 mm height was made of mild steel sheet (22 gauze). Hopper slope angle of 39.5° was provided taking into consideration 36^0 angle of repose of green walnut. The hopper was fitted on top of the dehulling unit for holding the green walnuts during the operation of the machine.



Dimensions in mm

Fig. 2: Views of motorized walnut dehuller

Dehulling unit

The dehulling unit was developed for shearing off the green hull of a walnut. It consisted of two casings; one being stationery, and the other rotating on the drive shaft. The stationary casing was mounted on the outer frame below the feeding unit. The outer casing cylinder was made of mild steel solid square cross-section iron rods of 8 mm thickness forming a cylinder of length 670 mm and diameter 360 mm. The rotating casing was made of galvanized iron mesh (35 mm × 30 mm perforations) of 230 mm diameter and 570 mm length, welded with the help of two MS rings and three MS strips on a MS solid shaft of 1030 mm length and 25 mm diameter. The clearance between the stationary casing and the rotating casing, between which the dehulling of walnuts took place,was adjustable in the range of 10- 45 mm for accommodating different sizes and shapes of walnut.

Outlet chute

A trapezoidal outlet chute was developed to collect the hulled walnuts from the hulling unit. It was made of mild steel sheet with length of 350 mm, top width of 280 mm and bottom width of 200 mm. A side wall of 80 mm was also provided to prevent spillage of walnut from the chute. In order to facilitate the discharge of hulled walnuts, the collecting chute had an inclination of 42º with the horizontal plane.

The total weight of the machine, including the power source, was 72 kg. Brief specifications of the machine components are given in Table 1.

Performance Evaluation of Walnut Dehuller

Performance evaluation of the prototype was done with walnut harvested from seedlings in Kupwara district of Jammu and Kashmir, India in association with Krishi Vigyan Kendra, SKUAST-K, Kupwara during September, 2014 (Fig. 3). The machine was also evaluated on walnut harvested from seedlings in Srinagar district of Jammu and Kashmir, India during September, 2015.

Fig. 3: Walnut dehuller in operation

Table 1. Specifications of components of walnut dehuller

Sl. No.	Item	Specification
1.	Overall dimensions (L×B×H), mm	1260 × 890×1630
2.	Power source	0.75 kW, single phase A.C. electric motor
3.	Power transmission unit	V-Belt and pulley (69 B), driver pulley: 62.5 mm, driven pulley: 350 mm
4.	Hulling unit	Cylinder and concave type Outer cylinder (MS square bar 8 mm) diameter 360 mm, length 670 mm Screen mesh unit: 35 x 30 mm perforation, length 570 mm, diameter 230 mm Clearance (between outer cylinder and mesh unit): 10-45 mm
5.	Hopper	Trough and tube shaped, MS Sheet 18 gauge, length: 421 mm, breadth: 290 mm, height: 460 mm
6.	Outlet Chute	M. S sheet, trapezoidal shape, length: 350 mm, top width: 280 mm, bottom width: 200 mm
7.	Hulling capacity, $t.h^{-1}$	0.260 at optimum peripheral speed and optimum heaping days
8.	Weight of machine, kg	72

Two independent parameters (number of heaping days and peripheral speed of dehuller cylinder) that mainly affect the performance of a dehulling machine were selected so as to maximize the percentage of nuts hulled and to minimize the degree of damage. In order to achieve this goal, the cylinder peripheral speeds were selected as L_1 (5.50 $m.s^{-1}$), L_2 (5.95 $m.s^{-1}$), L_3 (6.41 $m.s^{-1}$) and L_4 (6.87 $m.s^{-1}$); and the number of heaping days were chosen as H_1 (0 day), H_2 (2 days), H_3 (4 days) and H_4 (6 days). The number of heaping days was selected keeping in view to obtain maximum dehulling without discoloration as discoloration of walnut is directly related with number of heaping days. The levels of cylinder peripheral speed were taken based on preliminary observations. Sixteen combinations of cylinder peripheral speed and number of heaping days were evaluated. Each test was replicated thrice, and the average values reported. Effective throughput capacity, percentages of fully hulled walnuts and partially hulled walnut were recorded.

$$\text{Effective throughput capacity } (t.h^{-1}) = \frac{\text{Weight of dehulled walnut (t)}}{\text{Effective operating time (h)}} \quad ...(3)$$

$$\text{Percentage of fully hulled walnut (\%)} = \frac{\text{Weight of fully dehulled walnut (t)}}{\text{Weight of total dehulled walnut (t)}} \times 100 \quad ...(4)$$

$$\text{Percentage of partially hulled walnut (\%)} = \frac{\text{Weight of partially dehulled walnut (t)}}{\text{Weight of total dehulled walnut (t)}} \times 100 \quad ...(5)$$

$$\text{Hulling efficiency (\%)} = \frac{\text{Weight of dehulled walnut (t)} + \text{Weight of hull} + \text{Weight of damaged walnut (t)}}{\text{Weight of total green walnut fed (t)}} \times 100 \quad ...(6)$$

Statistical Analysis

The observed data was analysed for significant differences between treatments using factorial design in complete randomized design with Opstat software developed by CCSHAU, Hisar. The treatments consisted of combination of 4-levels of cylinder peripheral speed and 4-levels of heaping days with three numbers of replications.

RESULTS AND DISCUSSION

Hulling Quality of Dehulled Walnut

Effect of heaping period

The hulling of green walnuts depended upon the nature and maturity of the green hull. The mean effective throughput capacity, hulling efficiency, fully-hulled walnut percentage increased with increase in number of heaping days (Table 2), while partially-hulled walnut percentage and labour requirement decreased with increase in heaping days. It was observed that with increase in heaping period before hulling, the mean hulling efficiency and fully-dehulled walnut percentage increased, whereas mean partially-dehulled walnut percentage decreased (Fig. 4). However, with increase in heaping days the shell staining and kernel discoloration took place due to heat generation as also ingress of moisture and Juglone (5-hydroxy-1, 4-naphthalenedione) inside the walnut (Anon., 2017).

Table 2. Effect of peripheral speed and number of heaping days on hulling of green walnut

Peripheral speed(L), $m.s^{-1}$	Heaping days before hulling (H), days	Parameter				
		Effective throughput capacity, $t.h^{-1}$	Hulling efficiency, %	Fully-hulled walnut, %	Partially-hulled walnut, %	labour requirement, $man.h.t^{-1}$
5.50	0	0.065	45.11	10.55	89.52	15.37
	2	0.095	48.55	18.90	82.13	10.58
	4	0.103	55.74	27.70	72.13	9.70
	6	0.172	64.55	38.89	61.43	5.80
	Sub-mean	0.109	53.49	24.01	76.30	10.36
5.95	0	0.100	46.70	14.63	85.47	9.96
	2	0.127	54.69	24.40	75.63	7.86
	4	0.173	64.47	39.62	60.68	5.78
	6	0.223	67.35	49.70	50.27	4.48
	Sub-mean	0.156	58.30	32.09	68.01	7.02
6.41	0	0.116	47.57	18.45	81.57	8.62
	2	0.150	58.39	38.52	61.49	6.65
	4	0.260	79.55	77.87	22.53	3.85
	6	0.275	79.00	76.39	23.33	3.64
	Sub-mean	0.200	66.13	52.81	47.23	5.69
6.87	0	0.118	48.64	20.70	79.48	8.49
	2	0.152	60.27	44.56	55.60	6.58
	4	0.261	76.55	75.39	24.50	3.84
	6	0.276	76.51	74.19	24.80	3.63
	Sub-mean	0.202	65.49	53.71	46.10	5.64
Mean		0.181	62.69	44.81	55.19	6.38

Effective throughput capacity: CD ($p \leq 0.05$); L = 0.0015; H = 0.0015; L x H = 0.0030
Hulling efficiency: CD ($p \leq 0.05$); L = 0.643; H = 0.643; L x H = 1.287
Fully hulled walnut: CD ($p \leq 0.05$); L = 0.638; H = 0.638; L x H = 1.277
Partially hulled walnut: CD ($p \leq 0.05$); L = 0.875; H = 0.875; L x H = 1.750
Labour requirement: CD ($p \leq 0.05$); L = 0.119; H = 0.119; L x H = 0.237

Lowest hulling efficiency of 60.85 % was found when no heaping before hulling of green walnut was done. Highest hulling efficiency of 67.26 % was found with sample kept under 4 days of heaping before hulling. The mean hulling efficiency and fully-dehulled walnut were statistically at par at 4 and 6 days of green walnut heaping before dehulling.

Effect of cylinder peripheral speed

Hulling efficiency and percentage of fully-hulled walnut are major indicators of the hulling quality of green walnut. Hulling efficiency significantly varied with the peripheral speed of the cylinder (Fig. 5). Mean effective throughput capacity, hulling efficiency, fully-dehulled walnut percentage significantly increased with increase in peripheral speed (Table 2) while partially hulled walnut and labour requirement decreased with increase in peripheral speed of rotating cylinder. Highest mean hulling efficiency of 66.13 % was obtained at peripheral speed of 6.41 $m.s^{-1}$. However, mean throughput capacity, hulling efficiency and percentage of fully-hulled walnut were significantly similar at 6.41 $m.s^{-1}$ and 6.87 $m.s^{-1}$ peripheral speed of rotating cylinder. Similar results were observed for partially-hulled walnut percentage and labour requirement at peripheral speeds of 6.41$m.s^{-1}$ and

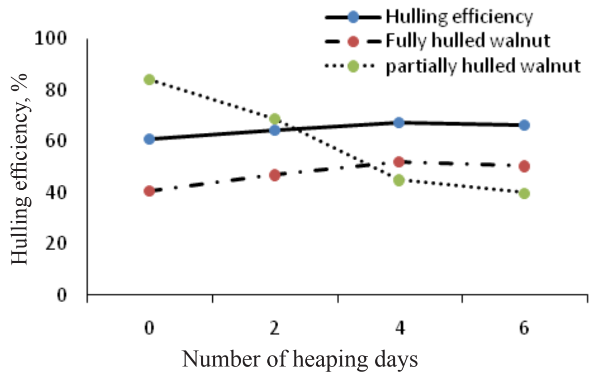


Fig. 4: Effect of number of heaping days on hulling efficiency

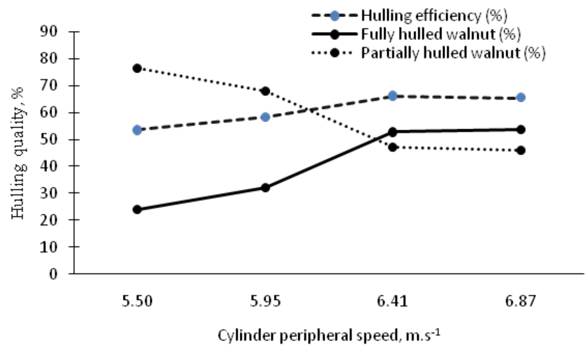


Fig. 5: Effect of peripheral speed of hulling on hulling quality

6.87 m.s^{-1}. Chegini and Makarichian (2015) had also reported similar trend on the effect of rotational speed on hulling efficiency of walnut.

Standardization of Machine Independent Parameters

Peripheral speed of hulling drum and heaping period for operation of the machine were standardized on the basis of quality of peeled walnut. Hulling efficiency and percentage of whole hulled walnut increased with increase in peripheral speed and number of heaping days. However, effective throughput capacity, hulling efficiency and percentage of whole hulled walnut were statistically at par at peripheral speed of 6.41 m.s^{-1} and 6.87 m.s^{-1}. Similarly, the effective throughput capacity, hulling efficiency and percentage of fully-hulled walnut were statistically at par when heaped for 4 days and 6 days. Also, the shell staining and kernel discoloration takes place with increase in heaping days due to heat generation and ingress of moisture and Juglone inside the walnut (Anon., 2017). Based on the findings, hulling drum peripheral speed of 6.41 m.s^{-1} and 4-day heaping period after harvest was considered for effective working of the machine. The effective throughput capacity, hulling efficiency and fully-hulled walnut percentage at selected operating parameters were 0.260 t.h^{-1}, 79.55 %, and 77.87 %, respectively (Table 2).

CONCLUSIONS

A motorized walnut dehuller was developed and evaluated. The portable compact machine hulling 4-day heaped (after harvest) green walnut at a drum peripheral speed of 6.41 m.s^{-1} could achieve effective throughput capacity of 0.26 t.h^{-1}, hulling efficiency of 79.55 % and fully-hulled walnut percentage of 77.87. The machine may be suitable for on-farm efficient hulling of walnut for small and medium farmers.

ACKNOWLEDGEMENT

The authors are thankful to the Horticulture Technology Mini Mission Mode-I, Indian Council of Agricultural Research, New Delhi for funding the project.

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Journal of Agricultural Engineering

Vol. 54 (4): October-December, 2017

Impacts of Climate Change on Stream Flow in the Gomti River Basin of India

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Article Info

Received : March, 2017
Revised accepted : November, 2017

***Key words*:** Climate change, Gomti river basin, MIROC GCM, stream-flow, SWAT model

ABSTRACT

Potential impacts of climate change on streamflow in the Gomti River basin of India were studied using the Soil and Water Assessment Tool (SWAT) model. The model was calibrated and validated using monthly streamflow data of four gauging stations of the basin. Climate change scenarios were developed using spatially downscaled (0.5×0.5°) MIROC3.2 (HiRes) GCM data for A2, A1b and B1 emission scenarios. The analysis showed that annual rainfall is likely to increase by 10 % to 18 %, 15 % to 24 %, and 19 % to 26 % during the 2020s, 2050s and 2080s, respectively. Mean annual stream-flows were projected to increase by 15 % to 38 %, 25 % to 44 % and 40 % to 55 % during the 2020s, 2050s and 2080s, respectively. Simulation results also indicated spatial and temporal variability in stream-flow in the basin, indicating the need for location-specific adaptation measure for planning of water use in the basin. The findings of the study could be useful for planning and managing water resources in the Gomti river basin for adaptation to climate change.

The Intergovernmental Panel on Climate Change in its 5th Assessment Report (IPCC, 2014) projected changes in water resources availability in almost all the regions of the earth due to climate change. The climate projections for India indicate that temperature is likely to increase by 3°C and rainfall is likely to increase by 10 – 20 % by the end of this century (IPCC, 2014; Narsimlu *et al*., 2013). Bal *et al*. (2016) projected a rainfall increase within a range of 15-24 per cent. Such a change in temperature and rainfall would affect water resources availability different sectors, particularly agriculture with serious implications on food and livelihood security. Therefore, quantifying the effects of climate change on spatial and temporal variability of water resources in river basin and sub-basin scale is vital for assessing the severity of the problem, and preparation of location-specific adaptation plans.

Impacts of climate change on hydrology and water resources availability have been studied by several researchers using different hydrological models and General Circulation Model (GCM) projected climate change scenarios (Wilby and Wigley, 1997; Ye and Grimn, 2013).The IPCC published a set of emissions scenarios in the Special Report on Emissions Scenarios (SRES) (Nakicenovic, 2000) to serve as the basis for assessment of future climate change impact. Among all SRES scenarios, most impact assessment studies generally employed A2, A1b and B1 emission scenarios representing high, medium and low emission scenarios, respectively. Gosain *et al*. (2011) studied the climate change impacts on Indian river basins using the Soil and Water Assessment Tool (SWAT) hydrological model and Providing Regional Climates for Impacts Studies (PRECIS) regional climate model (RCM) scenario for the A1b emission scenario. Their simulation results indicated increase in rainfall and associated increase in water yield in majority of the river basins for the period 2021-2050, and 2071-2098. Raneesh and Santosh (2011) investigated climate change impact on streamflow in Chaliyar watershed using the SWAT model and PRECIS-RCM generated climate change scenarios, and reported a reduction in streamflow in the basin. The SWAT model has also been used by Bharati *et al*. (2011) to investigate the possible climate change impacts on hydrology of the upper Ganga basin. They indicated that the dry and wet season flows under A2 scenario were lower than the baseline period at upstream locations, but higher at downstream locations of the upper Ganga basin. Singh and Gosain (2011) studied the impacts of climate change on the hydrological regime of Cauvery river basin in India using the SWAT hydrological model driven by the HadRM2 regional climate model projected scenarios. They indicated an intensification of the hydrological cycle in the future climate change scenario, which appeared to be significant on an annual basis. Islam *et al*. (2012) applied Precipitation Runoff Modelling System (PRMS), and reported 62 % increase in annual stream-flow under the combined effect of 4°C temperature rise and 30 % rainfall increase in the Brahmani river basin in India. Raje *et al*. (2014) used the variable infiltration capacity (VIC) macro-scale hydrologic model, and reported increases in runoff in most central Indian river basins (including Ganga) under future climate change scenarios.

Since hydrological conditions vary from region to region, the impact of climate change on regional water resources availability will vary from one river basin to another. Thus, for preparing local adaptation plans, it is important to understand the hydrological responses of a river basin in the backdrop of climate change. The Gomti river basin is a part of the Indo-Gangetic plain, and the discharge of the Gomti river is mainly due to monsoon rainfall (Dutta *et al*., 2011). Thus, temporal and spatial variations in rainfall under the changing climate scenarios will have reflective effect on water resources availability in the basin. An attempt was thus made to study the impacts of climate change on stream-flow and surface water resources in the Gomti river basin.

MATERIALS AND METHODS

Study Area

The Gomti river basin lies mainly in Uttar Pradesh (U.P.) state in north India, and its basin area is estimated as 30,437 km^2 (Dutta *et al*., 2011). Topography of the basin is undulating with the elevations ranging from 58 m to 238 m above the mean sea level (Fig. 1a). The climate of the basin is semi-arid to sub-humid tropical climate with average annual rainfall varying from 850 mm to 1100 mm. The Gomti river starts near Mainkot, about 3 km east of Pilibhit in Uttar Pradesh, and about 50 km south of the Himalaya foot-hills in India. This river is one of the important tributaries of the Ganga river, and it meets the main Ganga river at Kaithi in Varanasi (U.P.) after flowing 960 km in south and south-east direction. The Gomti river is characterized by sluggish flow throughout the year, except during the monsoon (rainy/wet) season when heavy rainfall causes a manifold (20-50 times) rise in its flow (Singh *et al*., 2013). The river hydrograph is highly controlled by the intensity and duration of precipitation during the monsoon season. Thus, any change in precipitation pattern under the projected climate change scenarios will have reflective effect on stream-flow hydrograph, water resources availability, and frequency and magnitude of flood events.

Modelling Tool

SWAT is the most widely used watershed model in many hydrological applications and climate change assessment (Arnold *et al*., 2010; Hoang *et al*., 2017). Therefore, this study used SWAT model and it is classified as a physically based basin-scale, continuous time and semi-distributed hydrologic model. The model has the capability to simulate hydrology, nutrients and pesticides dynamics and land management as well as plant growth on a daily time step (Arnold *et al*., 1998; Neitsch *et al*., 2011). It is also considered as one of the promising models for long-term simulations in predominantly agricultural watersheds.

In the SWAT model, the watershed is divided into a number of sub-watersheds that are then subdivided into hydrologic response units (HRUs) based on unique soil, slope and land-use characteristics. The model simulates the hydrology at each HRU using the water balance equation. The ability of SWAT to replicate basin hydrology at a variety of spatial scales on an annual or monthly basis has been confirmed in numerous studies (Gassman *et al*., 2007). In the present study, SWAT (SWAT-2012.10_1.14) version was used within the ArcGIS (ver.10.1) interface.

The SWAT model provided different methods for estimation of surface runoff, evapotranspiration and channel routing. The SCS curve number procedure (USDA SCS), the Penman–Monteith method (Monteith,1965), and variable storage coefficient method (William, 1969) for the estimation of runoff, evapotranspiration and channel routing, respectively, was used in the present study. Actual evapotranspiration in the SWAT model was estimated based on methodology developed by Ritchie (Ritchie, 1972).

For hydrologic simulation using the SWAT, the basin, sub-basins and stream network were delineated from the 90 x 90 m resolution Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM). Gomti river basin was divided into 21 sub-basins at the SWAT watershed delineation process and sub-basin discretization. It was further divided into 296 Hydrological Response Units (HRUs) at HRU definition and analysis process. These divisions were based on the variations of landuse, slope, and spatial distribution of soil in the basin.

Data source

The SWAT model requires inputs on weather, topography, soils, land cover and land management. Long-term 10-day average streamflow data of four available spatially distributed gauging stations (GS), namely Neemsar, Sultanpur, Jaunpur and Maighat (Fig. 1) were obtained from Central Water Commission (CWC), Lucknow and Varanasi.

Daily precipitation and air temperatures data of 14 districts (Barabankki, Hardoi, Kheri, Lucknow, Pilibhit, Shahjahanpur, Sitapur, Unnao, Udham Singh Nagar, Faizabad, Pratapgarh, Rae Bareli, Sultanpur, and Jaunpur) covering the entire basin for the period 1982–2010 were obtained from the National Initiative on Climate Resilient Agriculture (NICRA) project web portal (http://www.nicra-icar.in/nicrarevised/). In addition to this, long term (1972-2011) daily rainfall and temperature data of three India Meteorological Department (IMD) stations (representing Lucknow, Sultanpur and Jaunpur) were obtained from IMD, Pune.

The satellite remote sensing derived IWMI land-cover map (Thenkabail *et al*., 2009) of the study area at 56 m x 56 m resolution and 90 m x 90 m resolution SRTM DEM (http://gisdata.usgs.gov/website/Hydro- SHEDS/) were used for land use and topography data, respectively. The soil map of entire Ganga river basin at a resolution of 78 m x 78 m, developed by National Bureau of Soil Survey and Land Use Planning (NBSSLUP), Nagpur, Maharashtra, India was downloaded from the website http://gisserver.civil.iitd.ac.in and used as input to the model. The cropping pattern and management inputs on planting, harvesting and irrigation of individual crops were obtained from the available literature pertaining to the area (Hobbs *et al*., 1991).

The predominant land use in this basin, derived from IWMI land-cover map, was agriculture and 59 % of the area occupying irrigated conjunctive use double cropping (SWAT model class, R-08), and 32 % area was under irrigated surface water, double cropping (R-02) (Fig. 2). Crops were assigned to different IWMI land use categories (Fig. 2) considering the cropping pattern of Uttar Pradesh (U.P.) using IRS-P6 (AWiFS) data (Singh and Gosain, 2011). They reported the order of the cropping pattern in U.P. in terms of area as rice-wheat > sugarcane > rice-pulses >

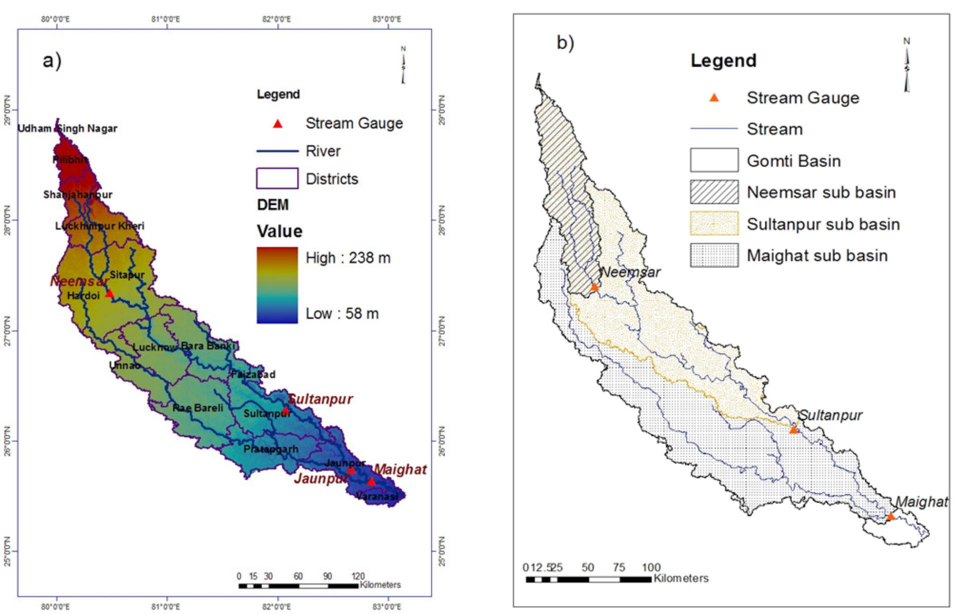

Fig. 1: a) Geographical distribution of gauging stations, major stream network and districts of Gomti river basin; b) Major sub-basins

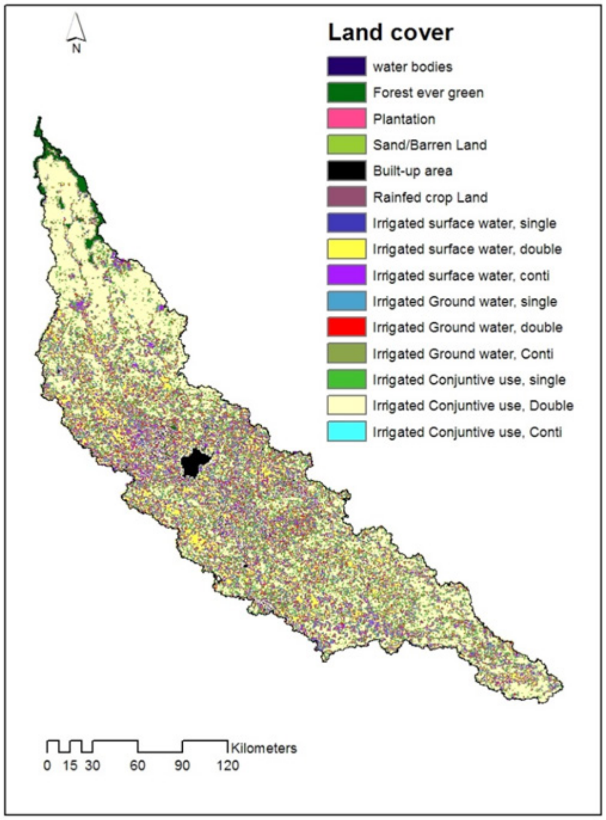

Fig. 2: Land cover map of Gomti river basin

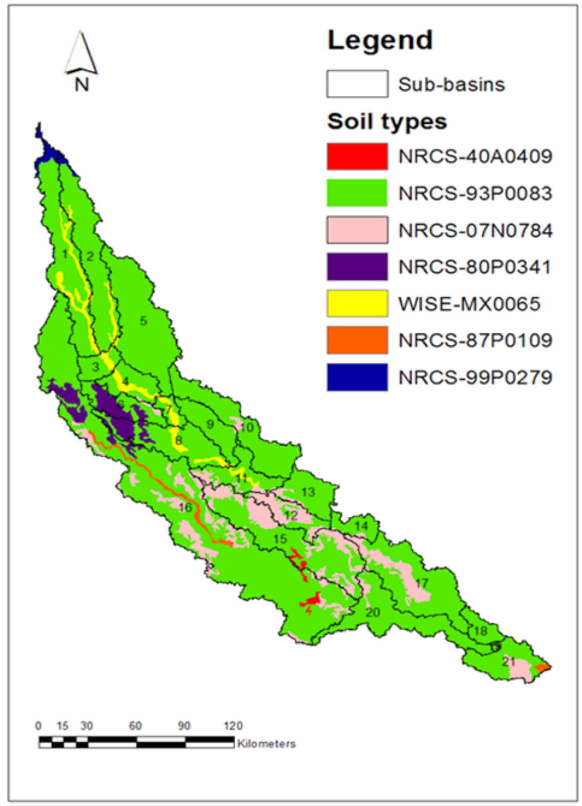

Fig. 3: Soil types and sub-basins map of Gomti river basin (sub-basins 1 – 21)

sugarcane-wheat, etc. Therefore, the land use category 'irrigated conjunctive use double cropping (R-08)' was considered as the irrigated rice and wheat grown area of the basin. 'Irrigated surface water, double cropping (R-02)' land use category was considered as rice and pulses growing area; and sugarcane crop growing area was assigned to landuse category of 'Irrigated surface water continuous (R-03)'. The land use type R-08, R-02, and R-03 occupied 59.58 %, 32.45 % and 1.38 % area of the basin, respectively. Soils of the area, extracted from NBSSLUP soil map, were predominantly alluvial deep soil (Fig. 3). NRCS 93P0083 (80 %) was the main soil type followed by the NRCS 07N0784 (11 %). Soil properties were taken from NBSSLUP soil map, Nagpur, Maharashtra, India.

Considerable part of the Gomti river basin is supplied with canal water from the Sharda Sahayak canal system. Therefore, water source for the simulation of the rice, pulses, and sugarcane was considered as the canal water in HRUs where canal is located, and SWAT recognized this source as outside unlimited source. For the other areas, where canal is not located, source of irrigation was considered as shallow aquifer located in the same sub-basin for rice. For irrigation of wheat, source of irrigation water was considered as shallow aquifer located in the same sub-basin where wheat is grown. Auto irrigation option was used to irrigate the crops, and plant water demand was set as a water stress identifier. Water stress threshold that triggered irrigation was initially set as 0.9 in the model. Automatic fertilization option for fertilizing the crops was selected because of the difficulty in obtaining fertilizer schedules for each crop at each HRU.

Calibration and validation of SWAT model

The SWAT model was parameterized for the streamflow from data of four spatially distributed gauge stations (GS), namely Neemsar, Sultanpur, Jaunpur and Maighat. As daily streamflow data were not available for the study basin, monthly streamflow data derived from monthly mean streamflow data were calculated from 10-day average streamflow.

The model was calibrated and validated by comparing the observed and simulated monthly streamflow for the period 1990-2000 and 2001-2008, respectively. The model was also run for 1982-1989 as warm-up period, which allowed the hydrologic model to cycle multiple times to minimize the effect of the user's estimate of initial values, such as soil water content, etc.; and brining the hydrological processes at an equilibrium condition. Before calibration and validation, a sensitivity analysis was performed using auto calibration tool SUFI- 2 (Sequential Uncertainty Fitting version 2) in SWAT CUP 2012 (Abbaspour, 2012). Most sensitive parameters were then calibrated manually considering their limits, and taking the support from SWAT CHECK that is embedded in SWAT 2012. Statistical parameters as Nash-Sutcliffe efficiency (NSE), Coefficient of determination (R^2), RMSE-observations standard deviation ratio (RSR), and Percent bias (PBIAS) were used to compare the simulated and measured flow (Moriasi *et al*., 2007). For assessing model performance, the model performance rating given by Moriasi *et al*. (2007) was primarily used.

The model was first calibrated for the sub-area contributing to the upper most gauging station (Neemsar), and then the model was calibrated for the sub-areas contributing to subsequent downstream gauging stations (Sultanpur, Jaunpur and Maighat). Herein after, these sub-areas were referred as Neemsar, Sultanpur, Jaunpur, and Maighat sub-basin, respectively (Fig. 1b).

The Neemasr GS, which was located at the upstream end of the basin, represented streamflow from the upper sub-basin; whereas Maighat GS located at the downstream end, represented the streamflow of the entire Gomti river basin. Based on literature survey (Parajuli *et al*., 2013; van Griensven and Meixner, 2007; Tattari *et al*., 2009), a total of 17 hydrological parameters were considered for the sensitivity analysis. Out of 17 hydrological parameters, 15 were identified as the most sensitive for all the four gauging stations, though their sensitivity varied among gauging stations (Table 1).

Generation of climate change scenarios

The climate change projection of the "Model of Interdisciplinary Research on Climate (MIROC)" GCM from the World Climate Research Programme's (WCRP's) Coupled Model Inter-comparison Project Phase 3 (CMIP3) climate projections multi-model data set [15] were used in this study. The MIROC 3.2 GCM was found to perform quite satisfactorily, with larger pattern correlation and smaller root-mean-square-differences for India (Anandhi and Nanjundiah, 2014) as well as eastern India (Das *et al*., 2012). The climate change projections of MIROC3.2 GCM has been used in several impact assessment studies (Rehana and Mujumdar, 2012; Naresh Kumar *et al*., 2013; Naresh Kumar *et al*., 2014). In this study, bias corrected and spatially downscaled (5° X 5°) (downloaded from www.engr.scu.edu/~emaurer/global_data/), MIROC 3.2 (HiRes) projected monthly rainfall and temperature data for high (A2), medium (A1B) and low (B1) emission scenarios was used. Perturbation (or delta change) method for generating climate change scenarios for the future periods of 2020s (2010–2039), 2050s (2040–2069) and 2080s (2070–2099) was used. The emission scenario A2 family of scenarios is characterized by a world of independently operating, self-reliant nations, continuously increasing population and regionally oriented economic development. The A1 scenario is characterized by rapid economic growth, a global population that reaches a peak in mid-century and then gradually declines, the quick spread of new and efficient technologies, and a convergent world. Based on the alternative directions of the technological changes in the energy systems, the A1 scenario family is grouped as A1FI (fossil intensive), non-fossil energy source (A1T) and a balance across all sources (A1B).The B1 scenarios describe a convergent world with population rising to a peak in mid-century and then declining as in the A1 scenario but with rapid changes toward a service and information economy, reductions in material intensity, introduction of clean and resource efficient technologies, and an emphasis on global solutions to economic, social and environmental stability. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than the A2 scenario, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines.

The delta change method, most commonly used approach for generating future climate scenarios (Ragab and Prudhomme, 2002; Sunyer *et al*., 2010; Khoi and Suetsugi, 2012) is based on the assumptions that the biases of the GCM were similar during the baseline and the future periods, and the temporal variability (daily to inter-annual) of the observed climate variables during the baseline period was maintained in the future simulated series (Ye and Grimm, 2013). These perturbed rainfall and temperature data for the

Table 1. Calibrated values of sensitive hydrological parameters of the SWAT model at four gauging stations in the Gomti river basin

Sensitivity rank	Parameter	Parameter description	Gauging station				SWAT ranges
			Neemsar	Sultanpur	Jaunpur	Maighat	
1.	ALPHA_BF (days)	Base flow alpha factor	0.57	0.57	0.57	0.57	0 – 1
2.	SOL_AWC (mm.mm^{-1})	Available water capacity	0.1 – 0.22	0.1 - 0.26	0.1 - 0.27	0.1 - 0.27	0 -1
3.	EPCO	Plant uptake compensation factor	0.95 – 0.98	0.85 - 0.9	0.89	0.9	0 - 1
4.	GW_DELAY (days)	Delay of time for aquifer recharge	94.69	94.69	94.69	94.69	0 – 500
5.	RCHRG_Dp	Aquifer percolation coefficient	0.28 - 0.29	0.25 - 0.3	0.24 - 0.28	0.23	0 – 1
6.	GW_REVAP	Groundwater 'revap' coefficient	0.02	0.02	0.02	0.02	0.02 – 0.2
7.	ESCO	Soil evaporation compensation factor	0.75	0.8	0.75 -0.8	0.8	0 -1
8.	CN2	Curve number	FRSE: 80, R02: 70 , R08: 70	FRSE: 80, R02: 72, R08: 72, URBN-85R03: 60	R02: 75 R08: 75	R02: 72 - 75, R08: 72 - 75	35 -98
9.	GWQMIN (mm)	Threshold water depth in shallow aquifer for flow	1.85	1.85	1.85	1.85	0 – 5000
10.	REVAPMIN (mm)	Threshold water level in shallow aquifer for revap	420	300 - 420	350 - 400	350 - 400	0 – 500
11.	SOL_K (mm/hr)	Saturated hydraulic conductivity	4 - 8.26	4.01 - 24.9	3.9 - 24	3.9 – 24	0 -2000
12.	OV_N	Manning's "n" value for overland flow	0.09 - 0.12	0.09 - 0.12	0.09 - 0.12	0.09 -0.12	0.01 -30
13.	CANMAX (mm)	Maximum canopy storage	FRSE : 1.5	FRSE : 1.5 R03: 1.1	-	-	0 – 100
14.	CH_K2 (mm/hr)	Channel effective hydraulic conductivity	5.5	6.3	5.5 - 0.6	5.5 - 0.6	-0.01 - 500
15.	SOL_BD (kg.m^{-3})x10^3	Bulk density (first two layers)	1.33 - 1.54	1.42 - 1.57	1.42 - 1.57	1.42 - 1.57	0.9 - 2.5

**Range indicates values for different HRUs and depths*

Note: R-08: Irrigated conjunctive use double cropping areas , R-02: Irrigated surface water, double cropping areas, R03: Irrigated continuous cropping, FRSE : Forested area, URBN: Built-up area

12 stations, which were used as climatic station in the model setup were input to the calibrated and validated SWAT model. Simulations were made for the projected climate change scenarios for three different future periods of 2020s, 2050s and 2080s; and the baseline periods (no change in rainfall and temperature) to estimate the changes in streamflow and surface water resources in the basin.

RESULTS AND DISCUSSION

Streamflow Calibration and Validation

Simulation results showed that there was a good agreement between the observed and the simulated streamflow hydrograph, both during calibration and validation periods. However, it could not detect some of the peak flows (Fig. 4). Table 2 shows the values of model performance indices NSE, RSR, PBIAS, and R^2 for both calibration and validation periods. According to the performance rating proposed by Moriasi *et al*. (2007), the model performance was good ($0.65<NSE\leq0.75$; $0.5<RSR\leq0.6$; and $\pm10<|PBIAS|\leq\pm15$) during both calibration and validation phase at Neemsar and Sultanpur; and during calibration phase at Maighat. The model performance at Jaunpur was satisfactory ($0.5<NSE\leq0.65$; $0.6<RSR\leq0.7$; and $\pm15<|PBIAS|\leq\pm25$) at both in calibration and validation periods. The model performance at Maighat station, which was

Table 2. Model calibration and validation performance statistics for monthly stream-flows at gauging stations

	Calibration				Validation			
Gauging station	NSE	RSR	PBIAS, %	R^2	NSE	RSR	PBIAS, %	R^2
Neemsar	0.72	0.52	-0.25	0.73	0.72	0.53	-1.1	0.76
Sultanpur	0.74	0.51	14.0	0.78	0.64	0.50	3.2	0.69
Jaunpur	0.62	0.61	12.4	0.66	0.54	0.67	4.0	0.63
Maighat	0.72	0.53	9.76	0.77	0.51	0.68	17.7	0.57

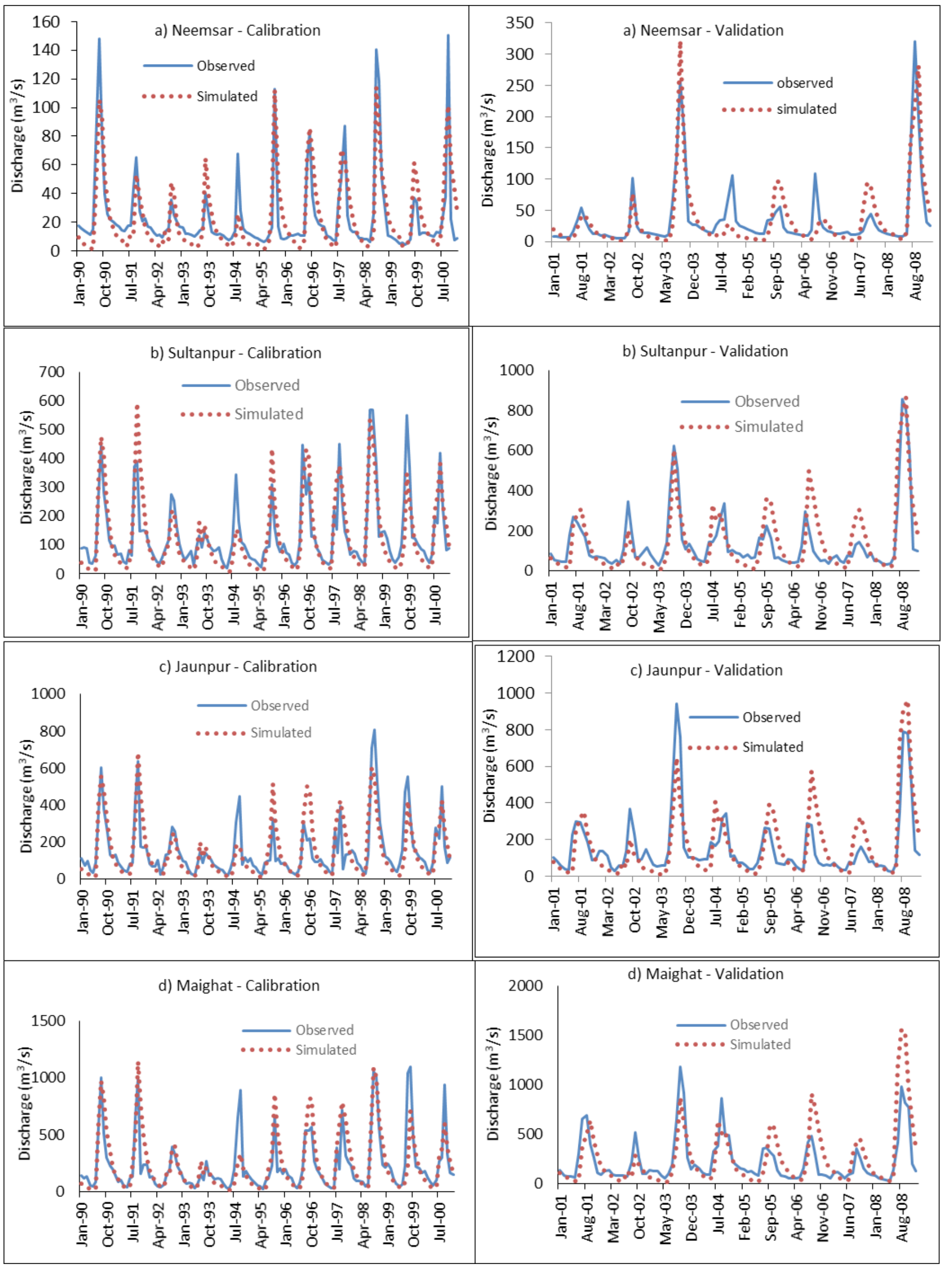

Fig. 4: Observed and simulated monthly flow hydrograph at a) Neemsar, b) Sultanpur c) Jaunpur and d) Maighat gauging station: calibration (left) and validation (right)

the lower-most gauging station of the Gomti basin, was good at the calibration phase and satisfactory at the validation phase. The coefficient of determination (R^2) was above 0.65 for all the four gauging stations, excluding Maighat station (0.57). Therefore, SWAT model performed satisfactorily in simulating monthly streamflows for the entire Gomti river basin, as the study used long-term records as well as records of four spatially dispersed gauging stations covering both very dry and very wet years for calibration and validation. This calibrated and validated SWAT model was used for climate change impact assessment.

Impacts of Climate Change on Rainfall and Temperature in River Basin

The changes in mean annual temperature and rainfall over the Neemsar, Sultanpur and Maighat sub-basins were examined separately. There was an increase in mean temperature as well as rainfall in the Gomti basin (Fig. 5, 6). Increase in temperature and rainfall were generally higher at the upstream sub-basin as compared to that of the entire river basin. Increase in the mean annual temperature at the upstream (Neemsar) sub-basins varied in the range of 0.7 ^{0}C to 0.9 ^{0}C, 1.6 ^{0}C to 1.9 ^{0}C, and 2.4 ^{0}C to 3.6 ^{0}C during the 2020s, 2050s and 2080s, respectively, depending upon the different emission scenarios.

For the mid sub-basin (Sultanpur GS) and the entire basins (Maighat GS), increase in the mean annual temperature varied from 0.7 ^{0}C to 0.8 ^{0}C, 1.5 ^{0}C to 1.8 ^{0}C, and 2.2 ^{0}C to 3.3 ^{0}C during the same time periods. Depending upon the emission scenarios,increase in the mean annual rainfall at the upstream sub-basin varied from 11 % to 20 %, 16 % to 25 %, and 26 % to 29 % during the 2020s, 2050s, and 2080s, respectively. For Sultanpur sub-basin, increase in rainfall were projected to vary in the range of 10 % to 19 %, 16 % to 23 %, and 19 % to 24 %; while for the basin upto Maighat GS this increase in rainfall was projected in the range of 10 % to 18 %, 15 % to 24 %, and 19 % to 25 % during 2020s, 2050s, and 2080s, respectively (Fig. 6 B).

Monthly analysis of projected changes in rainfall showed decrease in mean monthly rainfall during December, February, March, and April months under the A1B and B1 emission scenarios (Table 3). Maximum decrease was in December, both at the upstream and downstream sub-basins; followed by March, February and April months. At the upstream sub-basin, the decrease in mean rainfall during December varied from 12 % to 35 %, 1 % to 16 %, and 26 % to 34 % during the 2020s, 2050s and 2080s, respectively. At the downstream sub-basins, it varied from 7 % to 40 %, 1 % to 29 %, and 17 % to 34 % during the 2020s, 2050s

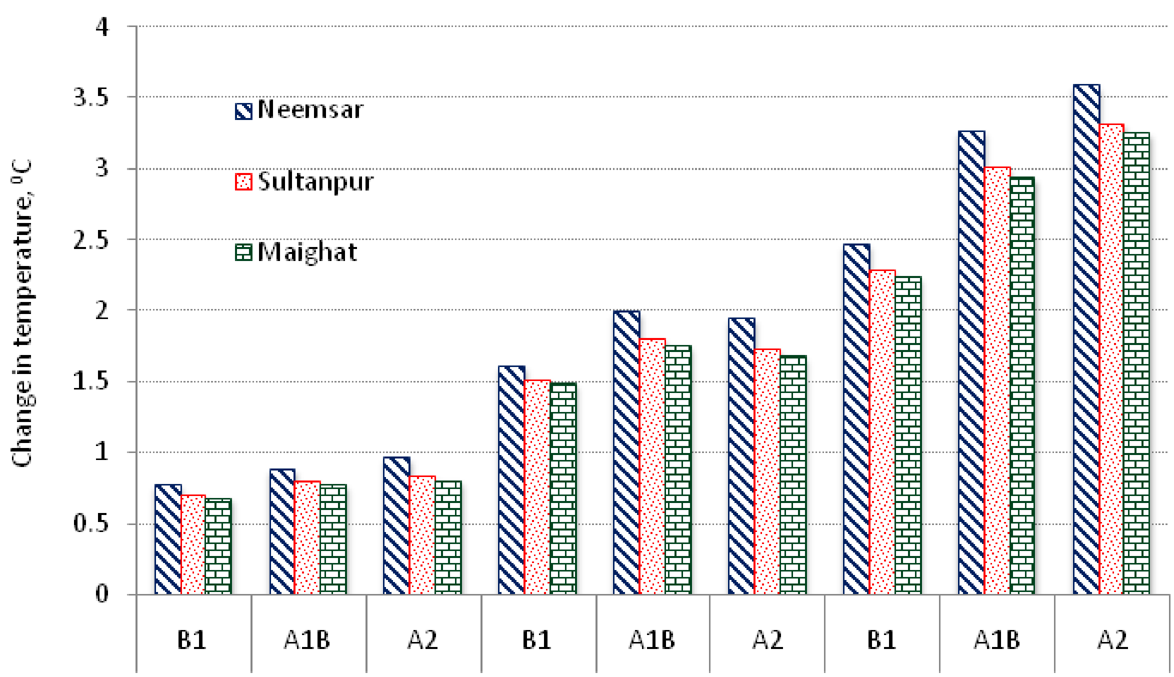

Fig. 5: Mean annual temperature change (^{0}C) over the baseline period in different sub-basins of Gomti river basin

Table 3. Changes (%) in monthly rainfall under different emission scenarios in Gomti river basin

Future period	Emission scenario	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
						Upstream sub-catchment							
2020s	A1B	8.07	-31.01	-38.61	-2.63	69.31	35.21	18.94	9.93	32.54	-3.84	37.82	-35.33
	B1	24.38	-25.08	18.98	-30.63	76.09	48.03	12.36	3.60	18.07	20.39	-7.53	-11.92
	A2	2.18	3.71	-34.67	-11.62	92.36	24.23	10.51	-11.09	28.17	3.24	-1.45	-22.72
2050s	A1B	-8.43	-18.74	-26.94	-2.61	75.61	42.22	14.92	4.98	33.95	10.25	7.42	-1.32
	B1	7.46	-15.92	11.84	11.08	21.60	52.29	24.18	7.20	29.31	43.54	-6.06	2.79
	A2	15.83	-0.90	-7.37	15.20	71.55	63.21	16.68	-6.64	20.07	-11.44	-64.08	-15.84
2080s	A1B	3.51	-12.14	-44.40	-43.20	91.09	52.70	21.29	8.11	44.83	95.88	14.63	-26.31
	B1	15.87	-4.05	-21.18	-44.65	19.00	27.38	31.79	25.70	37.31	27.12	-51.79	-34.03
	A2	7.54	2.54	-12.15	9.19	17.10	59.52	31.36	5.61	31.42	14.03	14.71	-28.60
						Downstream sub-catchment							
2020s	A1B	7.69	-41.92	-36.59	7.71	75.85	34.59	13.38	8.98	31.96	-1.59	33.45	-39.69
	B1	16.16	-27.84	12.25	-23.94	86.84	36.04	4.07	2.63	13.52	17.60	28.35	-7.24
	A2	-6.00	-7.41	-31.91	-0.39	89.24	20.39	9.30	-13.43	31.01	6.36	-32.95	-31.76
2050s	A1B	-11.85	-34.49	-55.91	205.32	255.54	40.73	16.23	7.83	46.01	23.93	61.11	-0.84
	B1	9.03	-23.85	-3.17	17.09	35.50	40.41	19.86	3.36	28.90	34.92	11.05	18.81
	A2	27.84	-3.34	-18.38	17.26	76.96	49.63	12.63	-1.75	23.01	4.42	-40.23	-29.41
2080s	A1B	3.83	-24.61	-32.22	-44.36	111.74	48.45	20.93	14.90	51.06	80.82	46.50	-16.57
	B1	16.37	-20.31	-18.48	-35.15	22.14	20.85	39.43	30.06	33.07	33.19	-42.61	-29.43
	A2	4.97	3.89	-16.03	3.14	22.23	50.41	31.15	8.35	21.33	27.44	44.43	-33.95

and 2080s, respectively. These reduction in rainfall and temporal as well as spatial variations in rainfall would affect the seasonal water resources availability in the different sub-basins, and would affect the rainfed winter crops in the basin.

Impacts of Climate Change on Streamflow

Changes (over base line period) in annual, monsoonal, and non-monsoonal streamflow and rainfall under A1B, B1 and A2 emission scenarios at three gauging stations are depicted in Fig. 6. In most of the cases, streamflow changes corresponded with the direction of changes of rainfall, particularly in annual and monsoon season. However, magnitude of streamflow changes was not consistent with the magnitude of rainfall changes during non-monsoonal periods.

Annual variations in streamflow

Changes in annual streamflow at the upper sub-basin (Neemsar) varied from 24 % to 59 %, 50 % to 75 %, and 77 % to 80 % during the 2020s, 2050s and 2080s, respectively. Streamflow changes at the middle sub-basin (Sultanpur) varied from 15 % to 35 %, 25 % to 42 %, and 47 % to 50 % during the 2020s, 2050s, and 2080s, respectively. Similarly, at the Maighat GS increase in streamflow ranged from 15 % to 38 %, 25 % to 44 %, and 40 % to 55 % during the same future periods of 2020s, 2050s, and 2080s, respectively (Fig. 6a, b). These results also revealed that changes of annual rainfall and associated changes of annual streamflow were greater at upstream (Neemsar) as compared to the respective changes upto mid sub-basin (Sultanpur) and the entire basin (Maighat GS), Fig. 6. However, the magnitudes of changes in rainfall as well as streamflow were low under A2 emission scenario as compared to that of under A1B and B1 emission scenarios. Narsimlu *et al.* (2013) also reported increase in annual precipitation and streamflow in the Upper Sind river basin, which is also one tributary river of Ganga river. Their modelling results also showed an annual precipitation increase of 4.3 % and 24.3 %, and associated streamflow increase of 16.4 % and 93.5 % during mid-century and end-century, respectively.

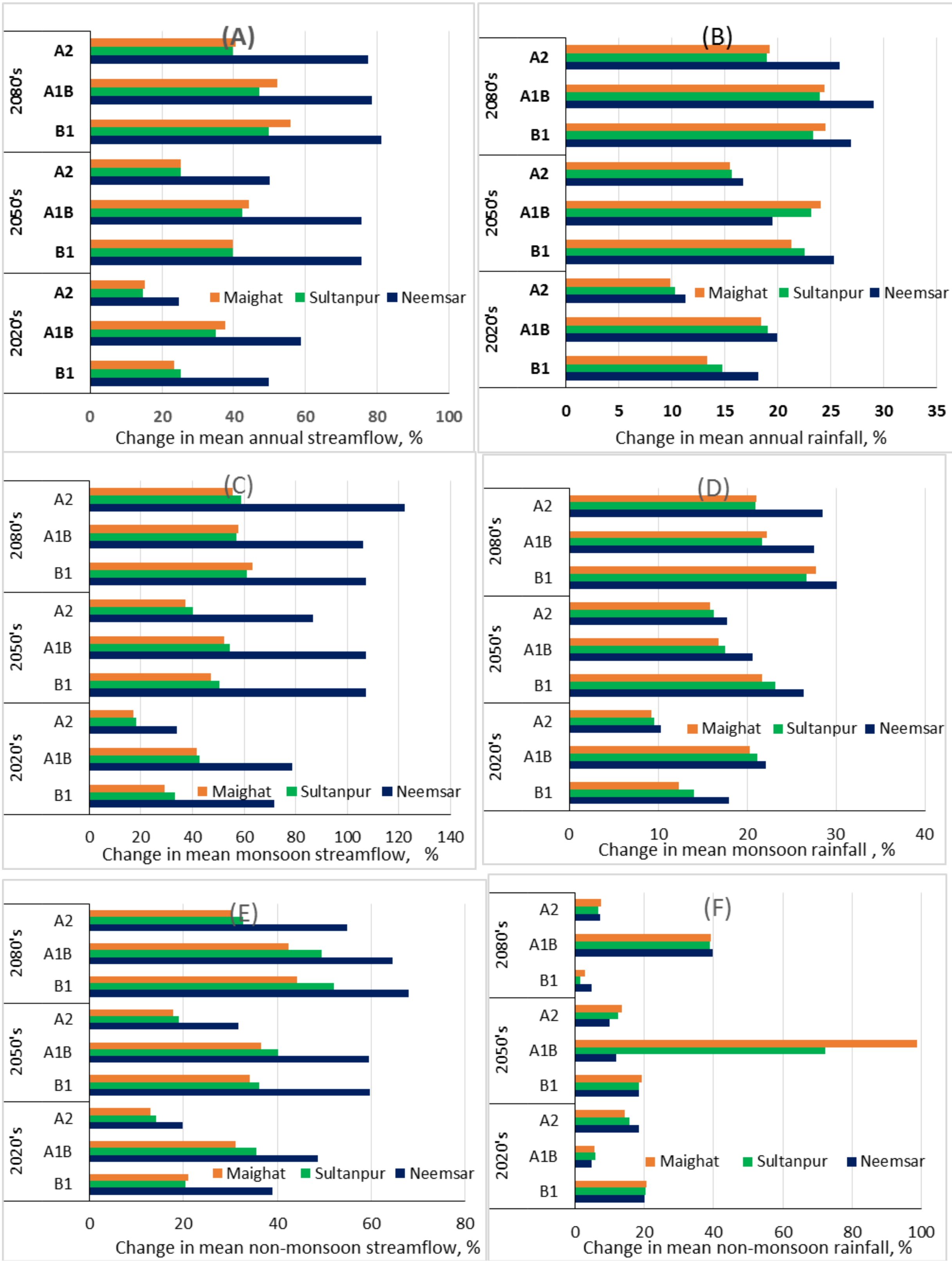

Fig.6: Change in mean annual (A), monsoon (C), and non-monsoonal (E), stream flow and change in mean annual rainfall (B), monsoon (D), non-monsoonal rainfall (F) over the baseline period under different climate change scenarios at three different gauging sites in Gomti river basin

Seasonal variations in streamflow

Analysis of the monsoonal and non-monsoonal variation of streamflow for the future time periods was done for different climatic scenarios. Monsoonal streamflow at Neemsar station was projected to increase by 34 % to 72 %, 86 % to 107 %, and 106 % to 122 % during the future time periods of 2020s, 2050s and 2080s, respectively (Fig. 6c.). Projected variation of monsoonal streamflow was comparatively lower in Sultanpur station, and it would vary in the range of 18 % to 43 %, 40 % to 54 %, and 56 % to 61 % during 2020s, 2050s and 2080s, respectively. These projections were further lower in the Maighat GS, and it would increase by 17 % to 41 %, 37 % to 52 %, and 55 % to 63% during the same time periods. These variations corresponded with the variations of monsoonal rainfall (Fig. 6.D). These increases in streamflow during monsoon season might further exacerbate frequency and magnitude of flood events. Changes in monsoon rainfall and streamflow for the climate change scenarios were consistent with the annual changes in rainfall and streamflow. However, non-monsoonal rainfall and streamflow behaved in different way as compared to the annual changes. Increase in the mean non-monsoonal streamflow at Neemsar sub-basins varied in the range of 19 % to 48 %, 32 % to 60 %, and 55 % to 68 % during the 2020s, 2050s and 2080s, respectively, depending upon the different emission scenarios. At Sultanpur, it is projected to increase by 14 % to 36 %, 19 % to 40 % and 33 % to 52 % during the same time periods. It variedfrom 13 % to 31 %, 17 % to 36 %, and 30 % to 44 % at Maighat stations during the 2020s, 2050s and 2080s, respectively. Compared to monsoonal changes (40 % to 76 % as an average for all durations and scenarios), changes during non-monsoonal time (27 % to 48 %) were estimated to be 48 % to 58 % lesser in magnitude (compared to monsoon changes) in all up-, mid- and down-stream side of the basin.

Monthly variations in streamflow

Future periods mean monthly streamflow in most of the months for nearly allclimatic scenarios were projected to increase. However, a decrease of streamflow in Sultanpur and Maighat GS was projected, especially in the month of March, under A2 and A1B emission scenarios. At the uppermost station, Neemsar, a comparatively higher increase of mean monthly streamflow was predicted for all months as compared to those at mid- and down-stream stations. This was in consistence with the monsoonal and annual increase of streamflow. The highest and lowest percentage of increase of mean streamflow at Neemsar station was projected in July and April months, respectively, in all climatic scenarios and all three future time periods (Fig 7). Generally, in most of the months, A2 scenario showed lower increase of streamflow. The projected increase of mean monthly streamflow at Sultanpur was comparatively lower than that of Neemsar. The highest increase of monthly streamflow at Sultanpur was projected in different monsoonal months (Fig.7). This pattern was similar at the most downstream stations of Maighat, which accounted for streamflow from the entire basin. Mean monthly streamflow at this station was shown to decrease in the month of March in all scenarios except A1Bin 2020s. These decreases of streamflow might affect the environmental flow of the Gomti river, and might affect the flora and fauna of the river. The spatial and temporal variability in streamflow warrants for location-specific adaptation measure for planning of water use of the basin.

Future Variations

The future variations of surface water resources of the entire basin were also analysed. The study considered the surface water resources (SWR) as the water flow contribution from sub-basins to generate stream-flow (Sun and Ren, 2013). The water yield (WYLD) in the SWAT model is defined as the summation of the surface water flow (Qsurf), lateral flow contribution to streamflow (Qlat) and the water that returns to the stream from the shallow aquifer (groundwater) contribution (Qgw) minus the total loss of water from the tributary channels as a transmission loss through the bed and finally reach the shallow aquifer as recharge (Arnold *et al*., 2012). Since there were no surface water reservoirs in the basin, the study considered WYLD in each sub-basins as SWRs. According to the assessment, average annual changes in SWRs of the entire basin varied from 20 % to 50 %, 36 % to 61 %, and 56 % to 89 % during the 2020s, 2050s and 2080s, respectively. These increases in SWRs also corresponded with the increase in streamflow in the basin, which ranged from 15 % to 38%, 25 % to 44 %, and 40 % to 55 % during the 2020s, 2050s, and 2080s, respectively (Fig. 6a, b). These results were also in confirmation with the previous study conducted by Gosain *et al*. (2011), where a 0.5 % decrease in water yield during mid-century and 27 % increase in water yield at the end of the century for the entire Ganga river basin were projected. The present simulation study based on SWAT and MIROC3.2 (Hires) GCM projections did not project any decrease in annual water yield in the basin.

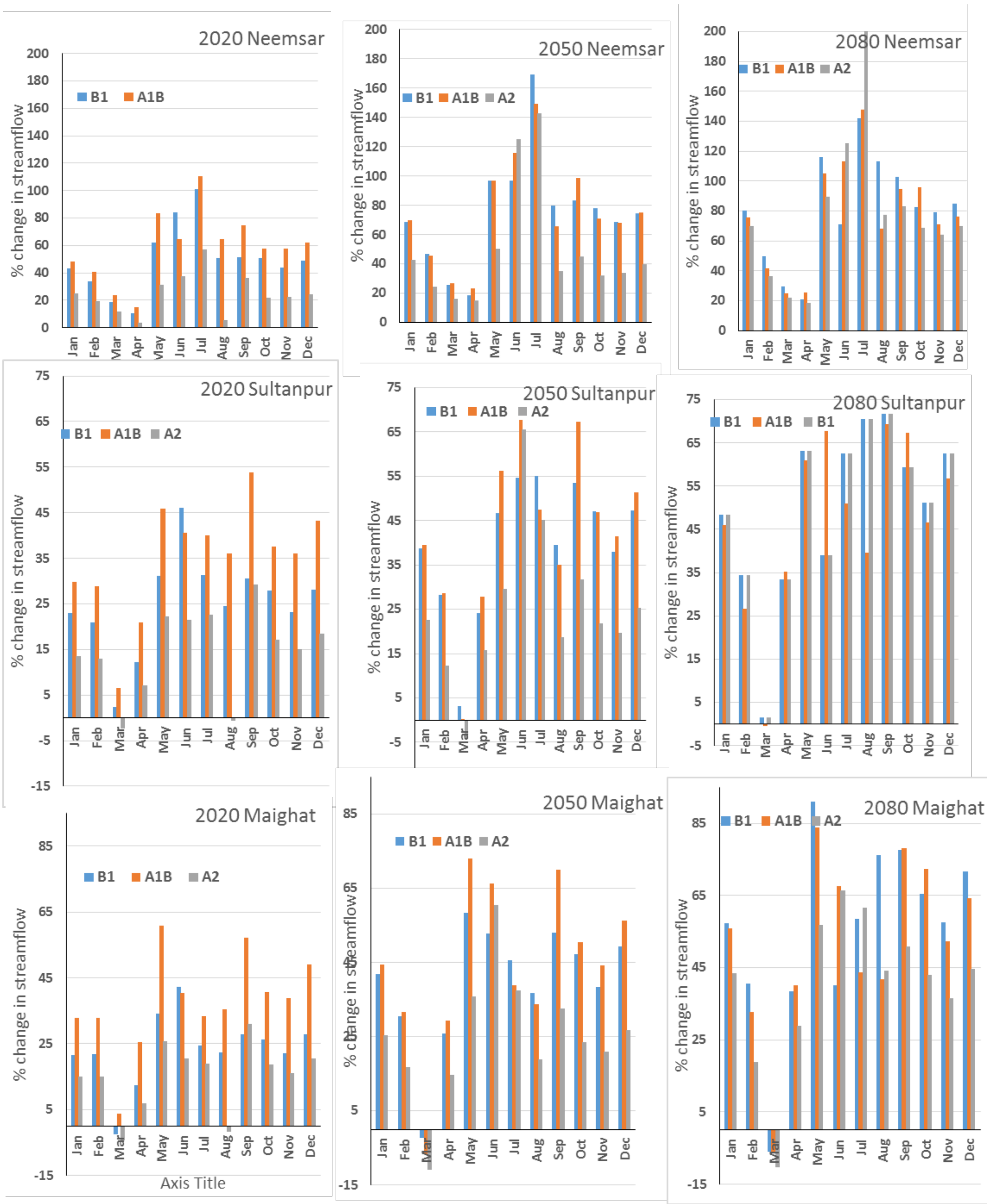

Fig. 7: Change in mean monthly stream-flow of Neemsar, Sultanpur and Maighat gauge stations in 2020s, 2050s and 2080s under different climate change scenarios in Gomti river basin

The simulation results provide valuable information on temporal and spatial variability of water resources in the basin under the changing climate scenarios, and will be helpful in planning in water allocation for different uses as well as deciding irrigation water management interventions for crop planning. However, these hydrological simulation studies are subjected to uncertainty due to model structure and model parameterization (Poulin *et al*., 2011). This study is based on the assumptions that the calibrated model will also remain valid for the future climate change scenarios. Further, the simulated changes in streamflow and SWRs for the future periods are based on the use of the same land use. Land cover and soil properties as at present. Therefore, projected results must be viewed under the assumptions of static land use condition.

CONCLUSIONS

Climate change impacts on streamflow in the Gomti river basin of India were studied using the Soil and Water Assessment Tool (SWAT) model and MIROC3.2 (HiRes) GCM climate change projections. Calibration and validation of the SWAT model showed that the model performed satisfactorily in simulating monthly stream-flows for the entire Gomti river basin. The study revealed that the average annual streamflow and SWRs might considerably increase in future. It also indicated that the changes of rainfall and associated changes of streamflow were greater at the upstream sub-basin (Neemsar) as compared to that of at the mid (Sultanpur) sub-basin and of the entire basin, particularly annual and monsoonal changes. As the discharge in the basin increased manifold during monsoon season, the projected increase in monsoon season streamflow and SWRs in future periods (2020s, 2050s, and 2080s) under changing climate scenarios, might further increase the frequency and magnitude of flood events. Though the simulation modelling results are subjected to various sources of uncertainty, the results obtained in this study could be useful for planning and managing water resources in the Gomti river basin through enhanced understanding of the possible impact of the projected climate change scenarios on streamflow and SWRs in the basin.

ACKNOWLEDGEMENT

Authors thank the Central Water Commission, Government of India, for providing streamflow data, NICRA, CRIDA and IMD for providing meteorological data, and to the Department of Agriculture, Uttar Pradesh for providing crop production data.

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Journal of Agricultural Engineering

Vol. 54 (4): October-December, 2017

Mechanized Planting of Carrot Seeds on Beds

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Article Info

Received : May, 2016
Revised
accepted : November, 2017

Key words: Carrot mechanized planting, ridge planting, broadcasting

ABSTRACT

Tractor operated inclined plate bed planter with total width of 2300 mm was used to plant carrot seed. Field trials on sowing of carrot seed were conducted using broadcasting, ridge and mechanical bed planting methods. Field capacity of mechanical method of planting was higher (0.5 $ha.h^{-1}$) as compared to 0.25 $ha.h^{-1}$ and 0.02 $ha.h^{-1}$ with the broadcasting and ridge methods, respectively. Seed rate requirement using machine was 6.9 $kg.ha^{-1}$ as compared to 18.75 $kg.ha^{-1}$ with broadcasting. The plant population of mechanical planting was higher ($5.25x10^5$ ha^{-1}) as compared to $4.0x10^5$ ha^{-1} and $4.38x10^5$ ha^{-1} by ridge and broadcasting methods, respectively. Root weight/yield of crop planted with machine was significantly higher (69.3 $t.ha^{-1}$) as compared to 51.75 $t.ha^{-1}$ and 48.38 $t.ha^{-1}$ obtained by ridge and broadcasting methods, respectively. Total planting cost of mechanical planting was lesser (4578 ₹.ha^{-1}) as compared to 11218 ₹.ha^{-1} and 38828 ₹.ha^{-1} with broadcasting and ridge methods, respectively. Total cost saving with carrot planter was 56 % and 87%, respectively, as compared to broadcasting and ridge planting methods. Break even point of carrot planter was 50 $ha.yr^{-1}$ with payback period of 50 ha use of the planter.

In Punjab, out of the total net sown area of 4.20 Mha, horticulture crops are currently grown in 0.25 Mha, accounting for 5.9 % of the net sown area. The area under vegetable crops was 0.23 Mha in the year 2015-16, and the area under root crops (including carrot) was 21.8 thousand ha (Anon., 2016). Vegetable crops can play an important role in diversification of agriculture in the country, especially in Punjab.

Carrot (*Daucus carota* L.) is an important vegetable root crop grown in spring, summer and autumn in temperate region and during winter in tropical region. Although, this root crop has been widely cultivated since long, yet its yield remained low (in the range of 25-30 $t.ha^{-1}$ in a maturity period of 100-120 days) due to adopted cultivation practices, and hence there is considerable scope to increase the production potential of carrot (Anon., 2014) with mechanization to improve farm efficiency and reduce drudgery of farm work force.

Sowing at optimum spacing is considered as an important parameter among agronomic practices for maintaining of adequate plant population per unit area for improved yield and produce quality. Wider spacing is found to be effective in vegetable crops for luxuriant crop growth due to less competition for nutrients, resulting in increased size of crop and ultimately higher yield and quality (Stefania, 2011). In Punjab, cultivation of root crops including carrot is mainly done manually requiring higher labour in sowing, thinning, weeding and harvesting operations and is the reasons for less area (21.8 thousand ha) under root crops (Anon., 2016).

Farmers in Punjab generally sow carrot seed either by broadcasting method or ridge planting method. Spacing of 450 mm between ridges and 75 mm between plants in a row is the common practice for this crop. In broadcasting method, there is uneven germination of seeds, uneven root size along with higher seed rate requirement (18.75 $kg.ha^{-1}$). Ridge planting method needs high labour during planting and thinning operations.

Carrot is mechanically sown and harvested in developed countries. Mechanical planters are also available for direct seeding of other crops. Small growers typically use less expensive mechanical seeders, but large growers can justify more expensive precision seeders. The planting mechanism of these planters has specially designed inclined plates for picking and dropping small seeds at delivery tubes. Inclined plate seed metering device was developed and evaluated in laboratory for singulation and uniform placement of carrot seeds with different treatment of coating viz. uncoated, biogas slurry coated and thirame coated (Yadachi *et al*., 2013). Metering device was tested at three inclinations of 40°, 50°and 60° using plates having cells with three shapes viz. triangular, semi-circular and slant cells. The selection of plate inclination and type of metering cell for the planter was purely based on average spacing, miss index, multiple index and quality of feed index. Slant type cell plate at inclination of 50° was recommended for sowing of coated seed of carrot. Valentin (2016) developed and evaluated a push type double row carrot seeder. The dropping efficiency and field efficiency of the seeder was 96.7 % and 88.2 %, respectively. The device was found to be 76 % faster than the conventional method of planting carrot seeds. Gautam (2016) developed, tested and evaluated an inclined plate planter to plant onion, carrot and radish on 1000 mm wide beds. The yields were 47.88 t.ha^{-1}, 25.20 t.ha^{-1} and 32.26 t.ha^{-1} for onion, carrot and radish, respectively. Field capacity of the machine was 0.164 ha.ha^{-1}, and the fuel consumption during sowing operation was 4.5 l.h^{-1}. The estimated cost saving was 94.5 % for onion and carrot, and 49.5 % for radish crop.

The present study was undertaken for mechanical planting of carrot seeds on beds maintaining proper depth and spacing to increase yield and quality of carrot roots along with lesser cost and labour requirement.

MATERIALS AND METHODS

Tractor operated Bed Planter

A commercial model of tractor operated bed planter (Fig. 1) with total width of 2300 mm using inclined plate metering mechanism was used for planting carrot seed. The inclined plate of 155 mm diameter had 47 numbers of grooves on its periphery (Fig. 2) to carry the seeds and drop in the seed tubes. The bed planter prepares three beds in one operation with top width of 400 mm. It could sow 4 rows on each bed with row-to-row spacing of 100 mm. A flat plate attached at the rear of each row provided proper soil coverage. Technical specifications of the planter are given in Table 1, and operational view (planting operation) of

Fig. 1: Operational view of bed planter

Fig. 2: View of inclined plate mechanism of mechanical bed planter

Fig. 3: View of bed planting of carrot with mechanical bed planter

the planter is shown in Fig. 3. In mechanical method, all unit operations of carrot planting were completed in a single pass with tractor operated planter. In the ridge planting method, most of the planting operations as sowing, fertilizer application, thinning of plants was carried manually.

Table 1. Technical specifications of tractor planter

Sl. No.	Parameter	Specification
1.	Tractor power required, kW	26 or more
2.	Total width, mm	2300
3.	Number of rows	12
4.	Row-to-row spacing on each bed, mm	120
5.	Bed-to-bed spacing, mm	675
6.	Type of metering mechanism	Inclined plate
7.	Diameter of inclined plate, mm	155
8.	Groove size (width x depth), mm	6.5 x 3
9.	Number of grooves on each plate	47
10.	Geometry of bed (Top width x bottom width x height), mm	400 x 675 x 300

Experimental Locations

Field trials on sowing of carrot (variety PC-34) were conducted using broadcasting, ridge planting and mechanical planting methods. The soil at PAU was alluvial, and the texture of soil was sandy-loam. The soil texture at farmer's field was loamy. Three locations (Table 2) were selected at the Research Farm of the Department of Vegetable Science, Department of Farm Machinery and Power Engineering, PAU, and farmer's field at village Bohn, Hoshiarpur. Data were collected during sowing and harvesting of carrots.

A study was conducted to compare the mechanical planting of carrot with conventional methods such as ridge and broadcasting. In the ridge method used for carrot planting, a tractor operated ridger was used for ridge making, Fig. 4. The spacing between ridge-to-ridge was 450 mm. The seed rate for ridge planting was 11.25 $kg.ha^{-1}$. In broadcasting method, sowing was done simply by manual broadcasting. The soil condition at the time of sowing was friable. The seed rate for broadcasting was 18.75 $kg.ha^{-1}$. Different variables as seed rate, seed depth, row spacing, plant spacing, plant germination and plant population were selected as per agronomic practices to observe the performance of carrot planter with other methods of planting. Field

Fig. 4: Operational view of tractor operated ridger for making ridges

Table 2. Location of field trials with date of sowing and harvesting

Sl. No.	Location	Area under trial, ha	Date of sowing	Date of harvesting
1.	Vegetable Research Farm, Department of Vegetable Science, PAU, Ludhiana	0.15	October 06, 2013	January 10, 2014
2.	Departmental Research Farm, Department of Farm Machinery and Power Engineering (FM & PE), PAU, Ludhiana	0.15	October 08, 2013	January 13, 2014
3.	S. Gurcharan Singh, Village Bohn, Distt. Hoshiarpur	0.30	September 29, 2012 September 27, 2013	January 02, 2013 January 04, 2014

capacity of the planter was also determined to evaluate the machine performance. Crop variables as root length, root width, ten root weight and yield were selected as dependent variables and data of these variables were observed and compared for finding the machine performance with other methods.

The study was conducted at different locations and the selected variables were observed at optimum forward speed of planter.

Five replications of each variable were recorded, and the average values of these replicated data are reported. Observed data was statistically analysed by using one-way ANOVA.

RESULTS AND DISCUSSION

Effect of Planting Methods

Field capacity, seed rate, sowing depth and plant population

Different attributes of carrot planting with different planting methods are given in Table 3.

Field capacity of mechanical planting (0.5 ha.h^{-1}) was higher than that of broadcasting (0.25 ha.h^{-1}) and ridge method (0.02 ha.h^{-1}). Carrot seed rate with mechanical planter was 6.9 kg.h^{-1}as compared to 18.75 kg.h^{-1} during broadcasting. Depth and row-to-row spacing in broadcasting method was uneven. The depth of seed varied from 15 to 35 mm. Sowing depth of ridge method and mechanical method was 25 mm and 30 mm, respectively. The plant population of mechanical planting was higher (5.25 x 10^5.ha^{-1}) as compared to 4.0 x 10^5.ha^{-1} and 4.38 x 10^5.ha^{-1} under ridge and broadcasting methods, respectively. Crop stand view of experimental plot planted with mechanical method is shown in Fig. 5.

Root length, root width and root weight/yield of carrot

Root length, root width and weight/yield data of harvested carrot at university research farm during harvesting of carrot crop, and is presented in Table 4.

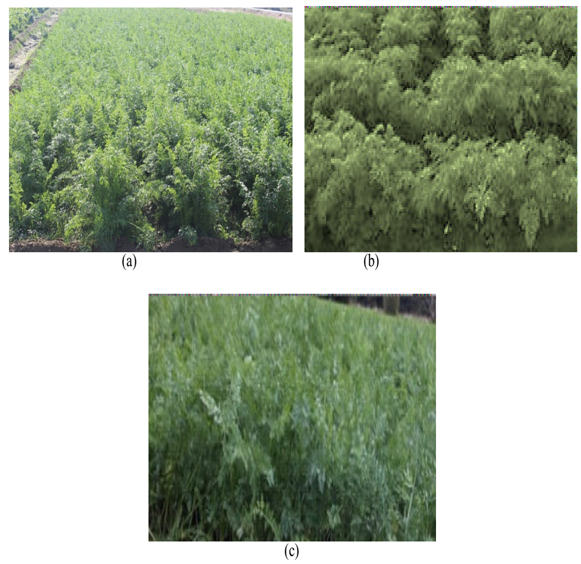

Fig. 5: Comparison of crop stand with (a) bed planter, (b) ridge method, and (c) broadcasting method

Table 3. Observed data during carrot planting as per agronomic practices

Sl. No.	Attribute	Broadcasting method	Ridge method	Mechanical Method
1.	Operations	• Manual broadcasting of seed and fertilizer • Ridges formed with tractor	• Ridges formed manually • Manual fertilizer application and sowing of seed • Thinning done manually	All operations done in single pass of tractor bed planter
2.	Field capacity, ha.h^{-1}	0.25	0.02	0.5
3.	Seed rate, kg.ha^{-1}	18.75	11.25	6.9
4.	Depth, mm	Uneven	25	30
5.	Row-to-row spacing, mm	-	450	120
6.	Plant-to-plant spacing, mm	-	75	80
7.	Germination (visual)	Uneven	More uniform	Uniform
8.	Plant population, x10^5.ha^{-1}	4.4	4.0	5.3

Average carrot length at harvest was 186, 239 and 227 mm under broadcasting, ridge and machine planting method, respectively. Root length and width did not have significant difference for ridge and mechanical methods, but comparatively were higher in ridge and machine planting methods than broadcasting method. Ten carrot root weight for broadcasting, ridge and mechanical methods were 951.0, 1130.0 and 1087.5 g, respectively. Carrot root weight/yield in plots planted with tractor planter was significantly higher (69.3 $t.ha^{-1}$) as compared to 51.75 $t.ha^{-1}$ and 48.38 $t.ha^{-1}$ in plots planted using ridge and broadcasting methods, respectively. This might be due to higher population of carrot plants when sown by using tractor operated bed planter.

Table 5 shows the root length and width, ten root weight and yield of carrot sown at farmers' field. Root length of carrot was 192 mm, 236 mm and 234 mm when sown by broadcasting, ridge and machine, respectively. Root length with broad casting method was significantly lower with ridge and mechanical methods. Ten carrot root weight for broadcasting, ridge and mechanical methods were 955.0 g, 1165 g and 1135 g, respectively. Root weight/yield of crop was significantly higher (69.6 $t.ha^{-1}$) with mechanical sowing as compared to 53.3 $t.ha^{-1}$ and 48.3 $t.ha^{-1}$ with ridge and broadcasting methods, respectively.

Economics Analysis

Economics of carrot seed planting using tractor operated planter was compared with existing broadcasting and ridge methods of planting. Costs on seed, labour, machinery along with yield advantage were calculated for all three methods of planting, Table 6.

Seed cost was lowest (3125 ₹.ha^{-1}) when planted using the planter as compared to 9375 ₹.ha^{-1} and 5625 ₹.ha^{-1} required during sowing under broadcasting and ridge methods of planting respectively. Overall, there was saving of 67 % and 45% in seed cost while planting of carrot with machine as compared to broadcasting and ridge methods, respectively. Tractor planter required 12.5 man-h.ha^{-1} of human labour as compared to 1062 man-h.ha^{-1} and 25 man-h.ha^{-1}, respectively, during planting under ridge and broadcasting methods. Labour cost was 50 % and 88% lower when planting was done using machine as compared to broadcasting and ridge methods, respectively. Total cost of planting using tractor planter was 4578 ₹.ha^{-1} as compared to 11220 ₹.ha^{-1} and 38827 ₹.ha^{-1}in case of broadcasting and ridge methods, respectively, resulting in corresponding saving of 56 and 87 per cent.

There was yield advantage of 20.5 $t.ha^{-1}$ and 18.75 $t.ha^{-1}$ when carrot was planted using the tractor planter

Table 4. Carrot root length, width and weight in experimental plots at University research farm

Method of sowing	Root length, mm	Root width, mm	Ten root weight, g	Yield, $t.ha^{-1}$
Broadcasting method	186.5^a	31.8^a	951^a	48.5^a
Ridge method (450 x 75 mm)	239.0^b	35.2^b	1130^b	50.3^a
Mechanical method by planter	227.0^b	34.3^b	1087.5^b	69.0^b
C D (5%)	2.61	0.21	54.40	3.12

Table 5. Carrot root length, width and weight at farmer's field

Method of sowing	Root length, mm	Root width, mm	Ten root weight, g	Yield, $t.ha^{-1}$
Broadcasting method	192.0^a	33.0	955^a	48.3^a
Ridge method (450 x 75 mm)	235.5^b	36.9	1165^b	53.3^a
Mechanical with planter	234.0^b	35.5	1135^b	69.6^b
(C D) (5%)	3.12	NS	144.6	3.15

Table 6. Economics of different planting methods

	Item cost	Broadcasting method (BM)	Ridge method (RM)	Mechanical planter method		
				Value	Saving over BM, %	Saving over RM, %
Seed*	Seed rate (kg. ha^{-1})	18.75	11.25	6.25	67	45
	Cost, ₹.ha^{-1}	9375	5625	3125		
Labour	Labour required (Man-h.ha^{-1})	25	1062.5	12.5	50	98
	Labour cost, ₹.ha^{-1}	781.25	33202.5	391.25		
Machinery	Machinery required		Tractor ridger	Tractor planter	0	-
	Machinery cost, ₹.ha^{-1}	1062	-	1062		
Total Cost #		11218.25	38827.5	4578.25	56	87
Yield	Yield, t.ha^{-1}	48.38	51.75	69.33	42	37
	Yield benefit/ha (@ ₹.5000/t)	241875	258750	346625		

**Seed cost: Rs. 500 per kg*

#Cost for chemicals, labour required for other operations are not included as main focus of the study was centred on the comparisons of different planting methods, and hence other operations were excluded

as compared to broadcasting and ridge methods, respectively, resulting in 42 % and 37 % yield advantage. The fixed and operational cost of the tractor operated planter was 73168 ₹.yr^{-1} and 522 ₹.ha^{-1}, respectively. Custom-hiring charge of the carrot planter was 2000 ₹. ha^{-1}. Therefore, breakeven point of the carrot planter was found to be 50 ha.yr^{-1} with payback period starting after 50 ha of use.

CONCLUSIONS

Field capacity of mechanical method of planting (0.5 ha.h^{-1}) was found to be higher as compared to 0.25 ha.h^{-1} by broadcasting and 0.02 ha.h^{-1} by ridge planting method. Carrot seed rate required by the planter was 6.9 kg.ha^{-1} as compared to 18.75 kg.ha^{-1} and 11.25 kg.ha^{-1} required by broadcasting and ridge planting method. Plant population achieved with mechanical planting (5.25 lakh.ha^{-1}) was higher as compared to 4.0 lakh.ha^{-1} by ridge and 4.4 lakh. ha^{-1} by broadcasting methods. Saving in total cost with use of machine planting was 56 % and 87 % compared to the other methods. Yield advantage of 42 % and 37 % could be achieved with machine seeding as compared to planting done using broadcasting and ridge methods. Breakeven point of carrot planter was 50 ha.year^{-1} and payback period could start after that point.

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ISSN: 0256-6524
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VOL. 54, No.4 October-December 2017

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