Computer Simulation for Haulage Performance of Power Tiller

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ABSTRACT

The presence of a large number of marginal and small land holdings in India has rendered the power tiller to be the most suitable farm equipment for field operations, in view of its compact size, profitability and versatility, but the transport work which is also required to carry the farm produce is yet to be proved. Keeping these in mind, user friendly software was developed for predicting the haulage performance of power tiller to meet requirements in educational and research organizations. The developed software requires input parameters such as power tiller, trolley and operating conditions. The developed software was validated by conducting experiments with a 6.7 kW power tiller using a suitable trolley on tarmacadam road at various payloads and road slopes. The draft, slip, fuel consumption and speed were measured and other haulage performance parameters were calculated based on measured values to validate the developed software. The results simulated by software indicate lower draft and slip in the range of 1-23 and 2-9% with respect to the experimental data, however, higher transport productivity was in the range of 3-12%.

Keywords
Software, power tiller, trolley, tarmacadam road, transport productivity, transport efficiency.

Notations

a	acceleration
b	section width of tyre,
Bn	mobility number
CG	centre of gravity
CI	cone index
Cn	wheel numeric
COT	coefficient of traction;
d	overall diameter of tyre
Ebp	actual input power
EPRa	actual engine power required;
F	gross tractive effort
FC	fuel consumption
FEI	fuel economy index
Fp	gross tractive effort by power tiller
g	acceleration due to gravity
GTR	gross traction ratio
h′	CG height of power tiller from ground
HoM	height of material;
ht	height of CG in the trolley from ground
Hv	vertical height of hitch point
L	distance from hitch point to trolley axle
L′	distance from hitch point to power tiller axle
Lp	distance of CG of power tiller from axle
Lt	distance of CG of loaded trolley from axle
MR	motion resistance
MRR	motion resistance ratio
NTR	net traction ratio
P	draft
r	rolling radius
RD	rim diameter,
Rp	power tiller wheel reaction
rp	rolling radius of power tiller wheel
rt	rolling radius of trolley wheel
Rt	trolley wheel reaction
S	wheel slip
sfc	specific fuel consumption
SRL	static loaded radius
TE	tractive efficiency
Tp	rolling trust on power tiller wheel
TP	transport productivity;
TPE	transport efficiency
Tt	rolling trust on trolley wheel
V	vertical force
Va	actual speed,
Vt	theoretical speed
W	dynamic weight
WPL	payload
Wp	weight on the power tiller
Wt	weight on the trolley
Xp	eccentricity of power tiller wheel
Xt	eccentricity of trolley wheel
δ	tyre deflection
θ	road inclination angle

1. INTRODUCTION

Farming practices in India have been shifting from labor intensive to relatively more capital intensive methods with simultaneous development of tractor and power tiller. In this country, about 75% farmers falls under small (land holding 1-2 ha) and marginal (land holding < 1 ha) category who cannot buy tractor for them power tillers are ideal power source for cultivation. Power tiller which is also known as two wheels, walk behind or hand tractor is a well-accepted power source for paddy cultivation in India as well as in many part of the World. The use of power tiller is increasing at steady pace in India. As an evidence, the sale of power tiller increased from 17,481 in the year 2004-05 to 35,294 in the year 2008-09 [1].

The adoption of power tiller is still slow as compared to the tractors in India because the annual hours use of power tiller are 300 h compared to 1000 h for tractor [2]. The annual hour uses are less because of its unsuitability for primary tillage operation in dry land [3]. However, power tiller is also used for transportation using trolley attached behind [2]. The annual use of power tiller can be increase by using transportation (haulage work) purposes which is possible upto a road slope of 6% [4]. Several researchers [5, 6 and 7] emphasize to evaluate the haulage performance of power tiller at varying surfaces and wheel slips. The relative importance of various factors that affect haulage performance, needs extensive field experiments, which is very costly and also time consuming. Some of the literature relating to tractor haulage performance is available [8, 9, 10 and 11] but no attempt has been taken so far for the power tiller. Therefore, the present study has been taken up to develop user friendly computer program for the haulage performance of power tiller and to validate it with the experimental data

2. THEORETICAL CONSIDERATIONS

Following theoretical and empirical models were used to develop the software for haulage performance of power tiller.

2.1 Rolling radius

Rolling radius (r) is defined as distance traveled by wheel in one revolution divided by 2π

$$r = \frac{2.5 \times (d/2) \times SLR}{1.5 \times (d/2) + SLR} \quad 1$$

Where, d = overall diameter = 1.5 b + 1.06 RD,
SRL = d - 2 δ, and

2.2 Wheel slip (S)

When a power tiller pulls a load, there is a reduction in distance traveled and/or speed that occurs because of flexing of the tyre and shear within the soil. Slip occurs any time a wheel or traction device develops pull (net traction). It is mathematically expressed as

$$S = \left(1 - \frac{V_a}{V_t}\right) \quad 2$$

2.3 Motion resistance ratio (MRR)

The rolling resistance is mainly caused by tyre flexing and energy loss in deforming the soil due to continually climbing out of the depression made. Coefficient of motion resistance or motion resistance ratio (MRR) is defined as the ratio of rolling resistance to the dynamic weight on a wheel.

2.4 Gross traction ratio (GTR)

Gross tractive effort (F) is the axle torque input converted to a pull force. Part of the F is required to overcome the motion resistance (MR) and the remaining is the net traction, also called drawbar pull (P). Therefore,

$$F = MR + P \quad 3$$

The gross traction ratio is defined as ratio of the gross tractive effort developed by the tractor to the dynamic weight on the traction wheels (powered wheel).

Brixius (1987) [12] expressed gross traction ratio (GTR) and motion resistance ratio (MRR) as a function of mobility number (Bn) and wheel slip (S). The mobility number was created by combining the wheel numeric ($C_n = \frac{CIbd}{W}$), deflection ratio (d/h), and section width-to-diameter ratio (b/d).

$$GTR = 0.88\left(1 - e^{-0.1B_n}\right)\left(1 - e^{-7.5S}\right) + 0.04 \quad 4$$

$$MRR = \frac{1}{B_n} + 0.04 + \frac{0.5 \times S}{\sqrt{B_n}} \quad 5$$

$$B_n = \frac{CI \times b \times d}{RWD}\left(\frac{1 + 5\frac{\delta}{h}}{1 + 3\frac{b}{d}}\right) \quad 6$$

2.5 Net traction ratio (NTR)

Net traction ratio is defined as the ratio of drawbar pull to the dynamic weight on the driving wheels.

$$NTR = \frac{p}{W} \quad 7$$

$$NTR = GTR - MRR \quad 8$$

2.6 Tractive efficiency (TE)

The tractive efficiency is the ratio of drawbar power to the axle power and is expressed as

$$TE = \left(1 - \frac{MRR}{GTR}\right) \times (1 - S) \quad 9$$

2.7 Transport productivity (TP)

It is defined as the product of payload transported and actual forward velocity.

$$TP = W_{PL} \times V_a \quad 10$$

2.8 Transport efficiency (TPE)

It is defined as the ratio of transport productivity to the actual input power (Ebp).

$$TPE = \frac{TP}{Ebp} \quad 11$$

2.9 Fuel economy index (FEI)

It is the amount of fuel consumed per unit payload over a unit distance. It is expressed in l/ton-km.

$$FEI = \frac{sfc \times Ebp}{TP} \quad 12$$

2.10 Mechanics of power tiller-trolley combination

The dynamic forces acting on the trolley and power tiller is shown in Figs. 1 and 2 respectively.

2.10.1 For trolley

Force parallel to the ground:

$$p = (W_t \times \sin\theta) + (W_t \times \frac{a}{g}) + T_t \quad 13$$

Force perpendicular to the ground:

$$V = W_t \cos\theta - R_t \quad 14$$

Taking moment about the point O:

$$R_t(L - X_t) + T_t H_v - W_t \cos\theta(L - L_t)$$

$$+(W_t \frac{a}{g} + W_t \sin\theta)(h_t - H_v)] = 0 \quad 15$$

Eccentricity: $T_t \times r_t = R_t \times X_t$ 16

Putting the values of T_t from Eq. (16) in Eq. (15), the dynamic weight on trolley wheels could be expressed by

$$R_t = \frac{W_t[(L-L_t)\cos\theta + (H_v - h_t)(\frac{a}{g} + \sin\theta)]}{[L - \frac{X_t}{r_t}(r_t - H_v)]} \qquad 17$$

2.10.2 For power tiller

Force parallel to the ground:

$$F_p = P + (w_p \sin\theta) + (w_p \frac{a}{g}) + T_p \qquad 18$$

Force perpendicular to the ground:

$$V = R_p - W_p \cos\theta \qquad 19$$

Taking moment about the point O:

$$R_P(L' + X_P) + (F_p \times H_v) - [(L' + L_p)W_p \cos\theta] + [(h' - H_v)(W_p \frac{a}{g} + W_p \sin\theta] - (T_P \times H_v) = 0 \qquad 20$$

Eccentricity: $T_p \times r_p = R_p \times X_p$ 21

Putting the values of T_p from Eq. (21) in Eq (20), the dynamic weight on the traction wheel could be expressed by:

$$R_p = \frac{W_p[(L_p + L')\cos\theta + (H_v - h'_t) \times (\frac{a}{g} + \sin\theta)] - F_p \times H_v}{[\frac{X_p}{r_p}(r_p - H_v) + L']} \qquad 22$$

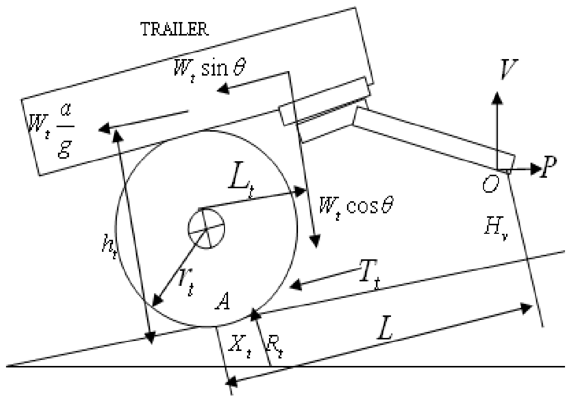

Fig 1: Free body diagram of the trolley

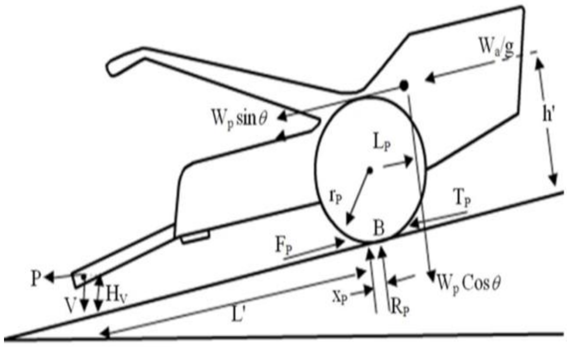

Fig 2: Free body diagram of power tiller

3. SOFTWARE DEVELOPMENTS

The software for calculating the power tiller performance parameters is developed in Visual Basic©. Using Brixius equations rolling radius (Eq. 1), gross traction ratio (Eq. 4) and motion resistance ratio (Eq. 5) are predicted for a given power tiller and soil condition. Slip is calculated by iteration process included in the program by comparing the net traction ratio calculated (Eq. 7) with that derived from the Brixius equation. The transport productivity, transport efficiency and fuel economy index is calculated by Eqs. (10-12). Dynamic weight on the power tiller wheel as well as on trolley wheel is calculated using Eqs.17 and 22, respectively. The flow chart of the developed software is shown in Fig. 3. The various input parameters are divided into three major sections namely (i) power tiller parameters (Weight of power tiller, Hitch height of power tiller above the ground, Hitch distance of power tiller from wheel axle, CG distance of power tiller from wheel axle, CG height of power tiller above the ground, Specific fuel consumption, Rated power of the engine, Rated engine speed, Width of power tiller wheel and Rim diameter of power tiller wheel), (ii) trolley parameters (Length of trolley, Width of trolley, Hitch height of trolley from the ground, Empty weight of trolley, CG height of trolley above the ground, CG distance of trolley from wheel axle, Distance

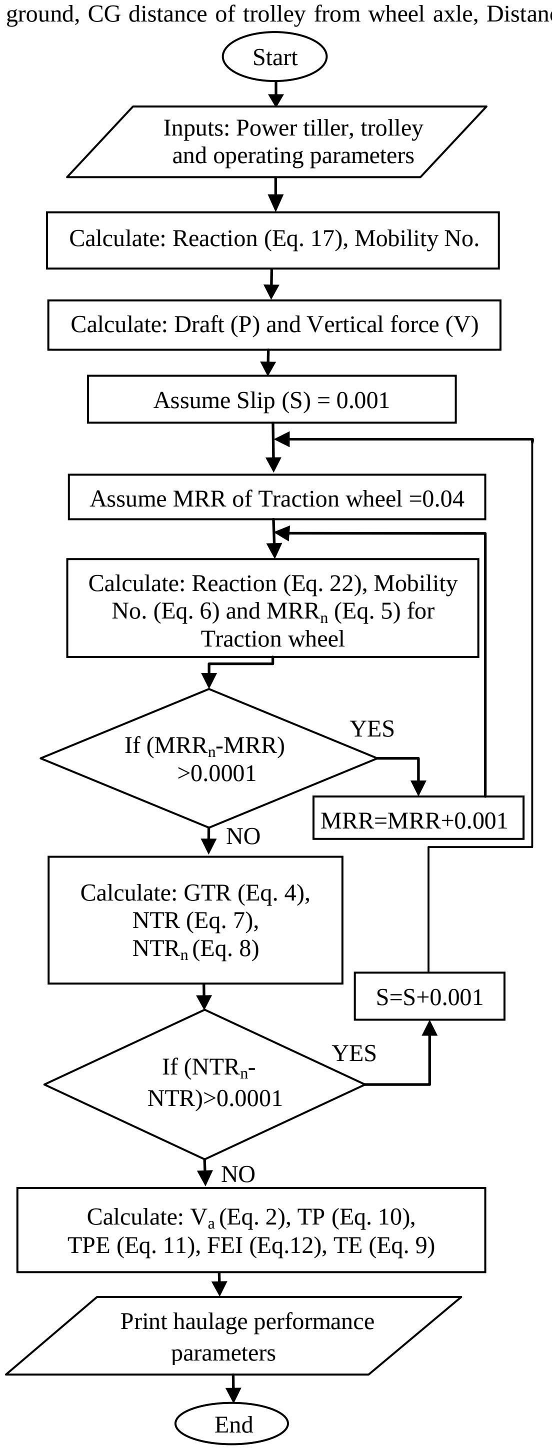

Fig 3: Flow chart for the developed software

of wheel axle from hitch point, Width of trolley wheel and Rim diameter of trolley wheel) and (iii) operation parameters (Cone index, Acceleration, Road slope, Speed of operation, Payload and Density of material). The output parameters included Draft, Coefficient of traction, Transport productivity, Actual engine power required, Transport efficiency, Fuel economy index, Tractive efficiency, Slip, Height of material, Actual velocity and fuel consumption. The input and output screens are shown in Figs. 4 to 6 [13].

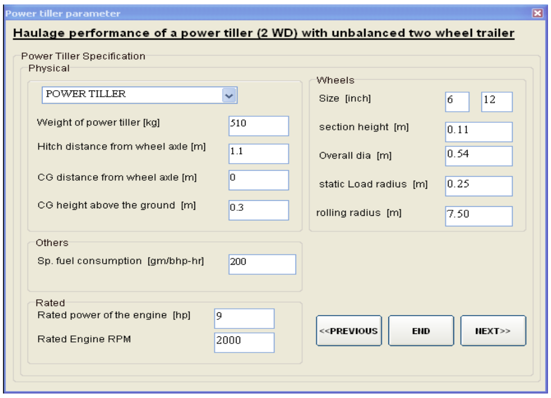

Fig 4: Power tiller input parameters screen

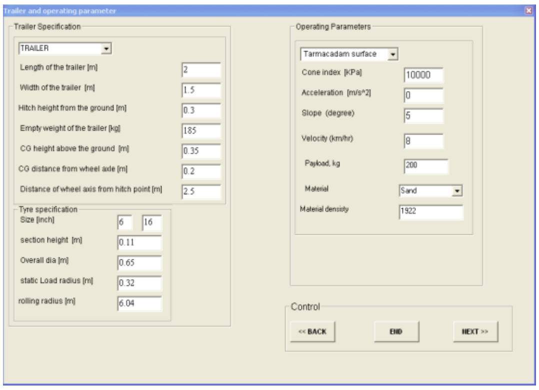

Fig 5: Trolley and operating input parameters screen

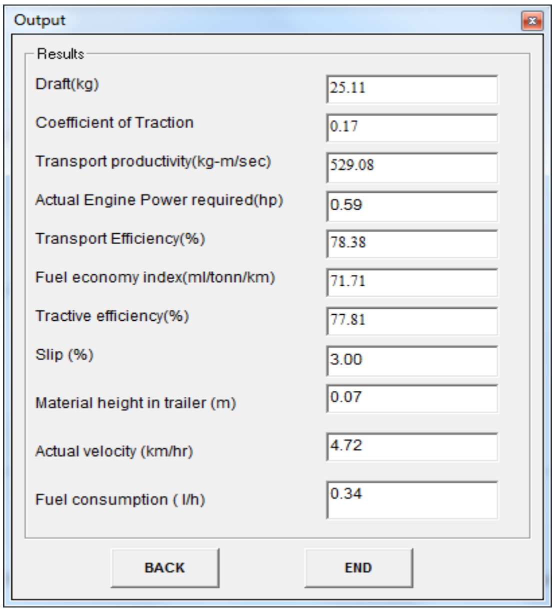

Fig 6: Output screen of the software

4. VALIDATION OF THE DEVELOPED SOFTWARE

In order to validate the developed software, the field experiments were conducted using power tiller with suitable trolley on tarmacadam road (cone index 10000 kPa). The input parameters of the selected power tiller and trolley are given in Table 1. The tests were conducted at three different slopes (0, 3 and 4.8%) as per the availability of site and payloads starting from 300 kg to maximum pull capacity at an interval of 300 kg. The experiments were conducted at varying theoretical speed of 4.87, 7.57 and 9.35 km/h which were achieved in three different gears of power tiller. Three replications were taken for each experiment to minimize the errors. The dependent parameters were draft, actual speed and fuel consumption. The draft was measured by suitably placing a 1000 kg capacity spring dynamometer between power tiller and trolley. The measurement of fuel consumption was carried out with the help of fuel measurement setup installed (Fig. 7) on the power tiller. An overall view of power tiller during experiment is shown in Fig. 8 [14].

Fig 7: Fuel measuring setup mounted on power tiller

Fig 8: View of power tiller with trolley during experiment

Table 1. Input parameters for selected power tiller and trolley for experiment

Input Parameters	Measured Values
Weight of power tiller	145 kg
Hitch distance from wheel axle of power tiller	1.1 m
CG distance from wheel axle of power tiller	0.0 m
CG height above the ground of power tiller	0.3 m
Tire width of power tiller	6 inch
Tire rim diameter of power tiller	12 inch
Specific fuel consumption of power tiller	200 g/hp/h
Input power of engine of power tiller	9 hp
Rated engine rpm of power tiller	2000 rpm
Length of the trolley	2 m
Width of the trolley	1.5 m
Hitch height from the ground of trolley	0.3 m
Empty weight of the trolley	85 kg
CG height above the ground of trolley	0.35 m
CG distance from wheel axle of trolley	0.2 m
Distance of wheel axis from hitch point of trolley	2.5 m
Tire width of trolley	5 inch
Tire rim diameter of trolley	19 inch

5. RESULTS AND DISCUSSION

The developed software was used to predict the performance of power tiller with a trolley at different operating conditions. The software predicted haulage performance parameters for different operating conditions is given in Table 2. Based on predicted values, the effect of slip on tractive efficiency for the haulage performance at tarmacadam road for various payloads, speeds and road slopes is shown in Fig. 9. It was observed that maximum tractive efficiency was found between 8-10% of the wheel slip. The effect of payload on predicted fuel economy index (FEI) at different slope is shown in Fig.10. The minimum FEI was found at 1500, 900 and 600 kg payload for 0, 3 and 4.8% road slope, respectively.

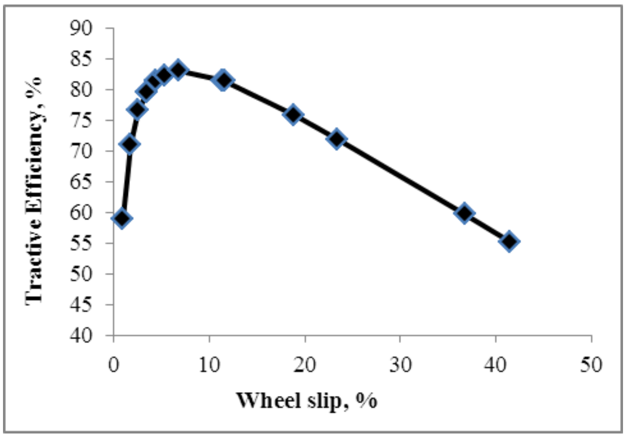

Fig 9: Effect of predicted wheel slip on tractive efficiency at varying operating conditions

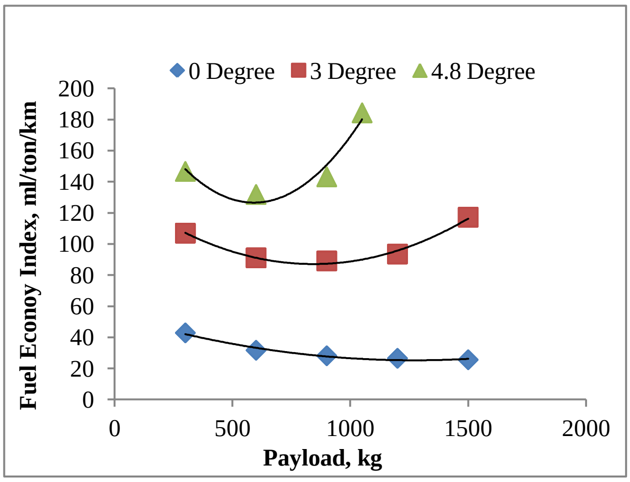

Fig 10: Effect of payload on fuel economy index at various slopes

6. VALIDATION OF DEVELOPED SOFTWARE

The comparison of the measured and predicted draft with respect to the payload at different road slope is shown in Fig. 11. It is observed that the draft increased with increased in payload as well as road slope for both measured and predicted cases. Further, it was also found that the software predicted draft values were 1-23% less than the measured values, however no significant different in two means was observed at 5% level as F-calculated was less than F-critical. The possible reason for variation in draft could be the non-uniformity of the road conditions. Similar comparisons were made for transport productivity (TP) at various speed and wheel slip at different slopes which are shown in Figs. 12 and 13, respectively. The close agreement between measured and predicted was observed for the TP. There was no significant difference between measured and predicted as F-calculated (0.43) is less than F-critical (3.95) at 5%. The insignificant difference in TP is due to the difference in the prediction of draft value. However, a significant difference in wheel slip (2-9%) was observed due the lower draft prediction which resulted in lower slip prediction.

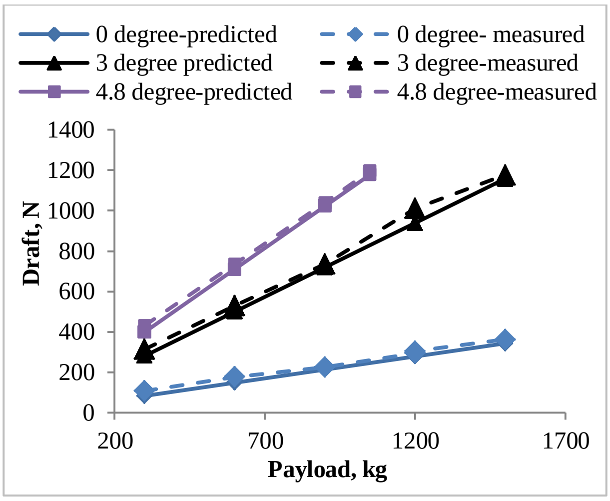

Fig 11: Comparison of draft at different payloads and slopes

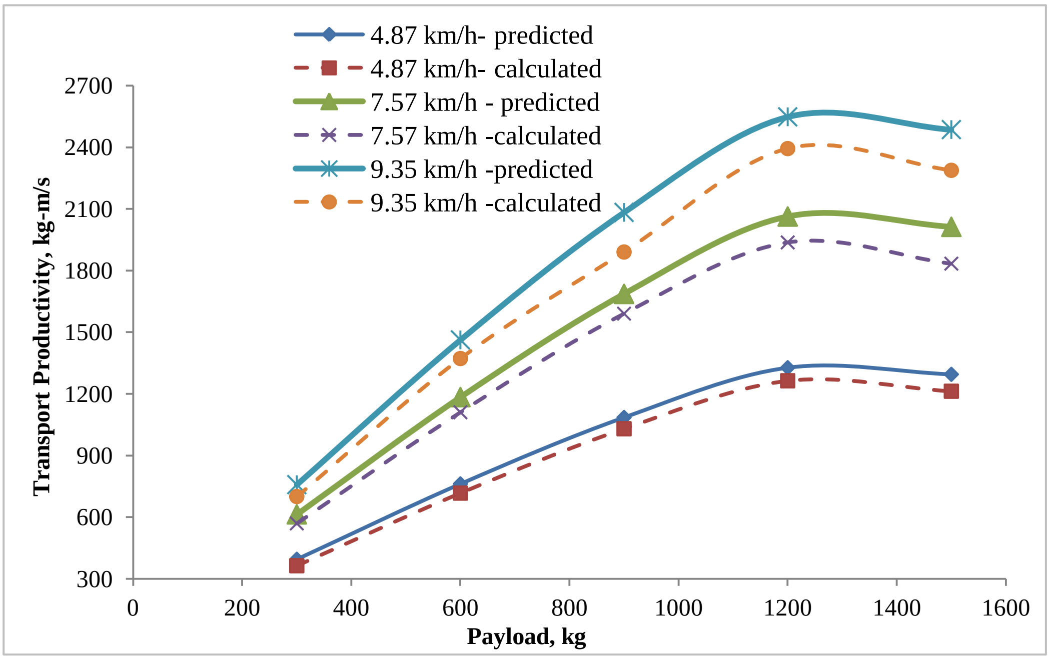

Fig 12: Comparison of transport productivity with different payloads and speeds at 3% slope

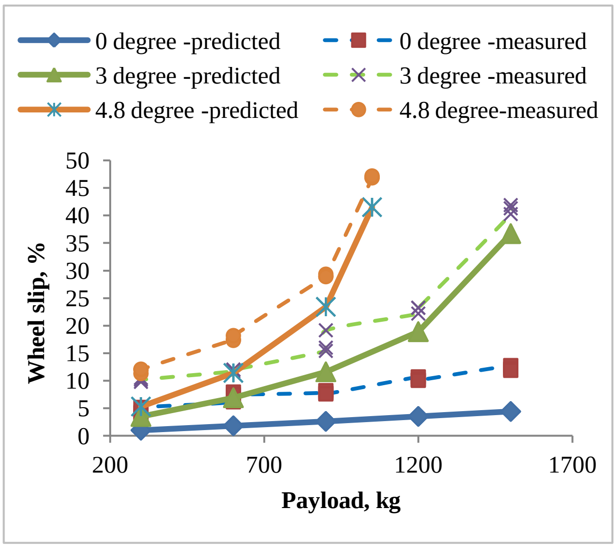

Fig 13: Comparison of slip at different payloads and slopes

7. CONCLUSIONS

A software package in visual basic was written as a part of this study to predict the haulage performance of power tiller at varying operating conditions. The simulation program mainly predict the draft, wheel slip, transport productivity, transport efficiency, actual engine power required, fuel economy index etc. The software was tested and verified for its operational behavior using real experimental data. The results found to under predict the draft (1-23%) and slip (2 -9%) for different payloads and road slopes. Further transport productivity was 3-12% more than the measured value. Hence, it is expected that the developed software package can be used by the power tiller designers and manufacturers to predict the performance parameters at various operating conditions without conducting exhaustive field test for further design modifications.

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Table 2. Software predicted haulage performance parameters for different operating conditions

Operating Parameters			**Output Parameters**										
Slope %	WPL, kg	Vt, km/h	Draft, kg	COT	TP, kg-m/s	EPRs, hp	TPE, %	FEI, ml/ton/km	TE, %	Slip, %	HoM, m	Va, km/h	FC, l/h
	300	4.87	8.5	0.06	404.99	0.27	60	42.81	58.86	1	0.05	4.82	0.34
	300	7.57	8.5	0.06	629.52	0.42	93.26	42.81	58.86	1	0.05	7.49	0.34
	300	9.35	8.5	0.06	777.55	0.52	115.19	42.81	58.86	1	0.05	9.26	0.34
	600	4.87	15.13	0.1	803.43	0.4	119.03	31.61	70.91	1.8	0.1	4.78	0.34
	600	7.57	15.13	0.1	1248.87	0.62	185.02	31.61	70.91	1.8	0.1	7.43	0.34
0	600	9.35	15.13	0.1	1542.53	0.76	228.52	31.61	70.91	1.8	0.1	9.18	0.34
	900	4.87	21.76	0.15	1195.33	0.52	177.09	28.08	76.52	2.6	0.16	4.74	0.34
	900	7.57	21.76	0.15	1858.04	0.82	275.27	28.08	76.52	2.6	0.16	7.37	0.34
	900	9.35	21.76	0.15	2294.94	1.01	339.99	28.08	76.52	2.6	0.16	9.11	0.34
	1050	4.87	25.07	0.17	1388.83	0.59	205.75	27.28	77.81	3	0.18	4.72	0.34
	1050	7.57	25.07	0.17	2158.81	0.92	319.82	27.28	77.81	3	0.18	7.34	0.34
	1050	9.35	25.07	0.17	2666.43	1.14	395.03	27.28	77.81	3	0.18	9.07	0.34
	300	4.87	28.66	0.2	394.76	0.66	58.48	106.89	79.44	3.5	0.05	4.7	0.34
	300	7.57	28.66	0.2	613.62	1.02	90.91	106.89	79.44	3.5	0.05	7.31	0.34
	300	9.35	28.66	0.2	757.91	1.27	112.28	106.89	79.44	3.5	0.05	9.02	0.34
	600	4.87	50.99	0.35	761.71	1.08	112.85	91.04	82.98	6.9	0.1	4.53	0.34
	600	7.57	50.99	0.35	1184.01	1.68	175.41	91.04	82.98	6.9	0.1	7.05	0.34
3	600	9.35	50.99	0.35	1462.41	2.08	216.65	91.04	82.98	6.9	0.1	8.7	0.34
	900	4.87	73.34	0.51	1084.88	1.51	160.72	89.05	81.34	11.6	0.16	4.31	0.34
	900	7.57	73.34	0.51	1686.35	2.35	249.83	89.05	81.34	11.6	0.16	6.69	0.34
	900	9.35	73.34	0.51	2082.88	2.9	308.57	89.05	81.34	11.6	0.16	8.27	0.34
	1050	4.87	84.52	0.58	1219.88	1.72	180.72	90.44	79.11	14.8	0.18	4.15	0.34
	1050	7.57	84.52	0.58	1896.19	2.68	280.92	90.44	79.11	14.8	0.18	6.45	0.34
	1050	9.35	84.52	0.58	2342.06	3.31	346.97	90.44	79.11	14.8	0.18	7.97	0.34
	300	4.87	40.71	0.28	387.4	0.89	57.39	146.56	82.31	5.3	0.05	4.61	0.34
	300	7.57	40.71	0.28	602.18	1.38	89.21	146.56	82.31	5.3	0.05	7.17	0.34
	300	9.35	40.71	0.28	743.77	1.7	110.19	146.56	82.31	5.3	0.05	8.85	0.34
	600	4.87	72.45	0.5	724.89	1.49	107.39	131.77	81.46	11.4	0.1	4.31	0.34
	600	7.57	72.45	0.5	1126.78	2.32	166.93	131.77	81.46	11.4	0.1	6.71	0.34
4.8	600	9.35	72.45	0.5	1391.73	2.87	106.18	131.77	81.46	11.4	0.1	8.28	0.34
	900	4.87	104.2	0.72	940.07	2.1	139.27	143.11	71.91	23.4	0.16	3.73	0.34
	900	7.57	104.2	0.72	1461.25	3.27	216.48	143.11	71.91	23.4	0.16	5.8	0.34
	900	9.35	104.2	0.72	1804.85	4.04	267.39	143.11	71.91	23.4	0.16	7.16	0.34
	1050	4.87	120.08	0.83	837.59	2.41	124.09	184.23	55.18	41.5	0.18	2.85	0.34
	1050	7.57	120.08	0.83	1301.96	3.75	192.88	184.23	55.18	41.5	0.18	4.43	0.34
	1050	9.35	120.08	0.83	1608.11	4.63	238.24	184.23	55.18	41.5	0.18	5.47	0.34