Deflection and Contact Characteristics of a Power Tiller Tyre

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Abstract

The power tillers or hand tractors are extensively used by small (1-2 ha holdings) and medium (2-4 ha holdings) farmers in predominantly rice-growing states in India for roto-tilling, plowing, puddling, intercultivation, harvesting, transportation etc. The vertical deflection and contact area of a pneumatic tyre (6.00 x 12 - 4 ply rating) of a popular 6.7 kW power tiller were determined at 2.38-2.87 kN normal loads and 80-200 kPa inflation pressure on a rigid flat surface. Both deflection and contact area varied linearly with inflation pressure in the range of normal loads selected for the study. The empirical equations were developed to predict the deflection and contact area of the tyre. Further, the power tiller tyre considered for the study followed the modified universal characteristics of a tyre. However, both empirical equations and universal characteristics equation of tyres could be used to predict tyre behaviour under various operational parameters.

Key words : deflection, contact area, ground pressure, universal characteristics

Introduction

If the 1980s witnessed India attain self-sufficiency in food, it was the 1990s that earned a place for it among the major food grain exporting countries (Siddiq, 2002). This is mainly owing to the extensive use of tractors, power tillers, transplanters, sprayers, harvesters, threshers and other power driven equipment and implements, in addition to high yielding variety seeds, fertilizers, plant protection chemicals and irrigation. Thus, farm mechanization in general and tractors and power tillers in particular have created a very positive and creditable impact on agricultural production and productivity. At present, a total of about 20,00,000 tractors and 66,000 power tillers are in use in Indian farms. Though India has become the largest market for tractor in the world with the sale of over 2,73,000 tractors a year, only 16,891 power tillers were sold during 1999-2000 (Anon., 2000). The lower use and sale of power tillers as compared to tractors could be attributed to lower tractiveability of power tiller for use in draft operations and its suitability to small and fragmented holdings for roto-tilling. However, they are the major sources of farm power in predominantly rice-growing states like West Bengal, Tamil Nad, Karnataka, Kerala, Assam and Andhra Pradesh. Due to the entry of new Chinese and Korean power tiller manufacturers, the sale figure of power tillers is further expected to rise and reach to about 50,000 power tillers per year by the end of 2020 (Singh and Doharey, 1999). In addition to roto-tilling, power tillers are used for plowing, puddling, intercultivation, harvesting, transportation and as prime movers for operation of irrigation pumps and threshers.

Though manufacturers supply pneumatic tyres and cage wheels for power tillers, pneumatic tyres are mostly preferred for tilling under dryland conditions and transportation. The tractive effort developed by the pneumatic tyres for these operations depends upon several soil-tyre and operating parameters. However, stresses occurring between the pneumatic tyre and supporting surface determines the amount of traction the tyre develops (Sharma and Pandey, 1996). Stress at the contact surface vary with the inflation pressure and normal load on the tyre, soil and tyre deformation/distortion and soil-tyre contact area (Yong, 1980). If the ground is sufficiently soft and the sum of inflation pressure and the pressure produced by the stiffness of the carcass is greater than the maximum pressure that the tyre can support at the lowest point of the tyre circumference, the tyre will remain round like a rigid wheel (rigid mode of operation). On the other hand, if the terrain is firm enough, a portion of the circumference of the tyre will be flattened (elastic mode of operation). In both cases, soil deformation results in the formation of a rut, but as the rut depth decreases, then the case of the wheel running on soil approaches that of a wheel running on a rigid surface (Plackett, 1987). Thus, the behaviour of the tyre on the soil surface is an important criterion and the study of tyre behaviour on a rigid flat surface prepares the way for further study of tyre behaviour on soil (Sharma and Pandey, 1996).

Bidermahn (1963) modeled and provided a universal characteristics equation of a tyre based on deflection, normal load, inflation pressure and carcass pressure of a tyre. Abeels (1976) investigated the effect of tyre load and construction on the width of the maximum enlargement of a tyre, length of contact patch and shape of contact patch. Komandi (1976) derived empirical relationships for tyre contact width, contact length and contact area. Ageikin (1987) and Koolen and Kuipers (1983) have given expressions for the elliptical contact area between a pneumatic tyre and a hard surface. Upadhyaya and Wulfsohn (1990) developed the mathematical expression for the 2-D contact length, contact width and contact area and reported that the 2-D contact area was elliptical when the tyre deflection was small and became rectangular with curved edges as the deflection was increased. Schwanghart (1991) reported a simplified model for predicting the contact area, contact pressure and compaction under tyres in soft soils and found that at rated normal loads and appropriate inflation pressure, the ground pressure of a group of tyres in loose sandy loam soil is independent of the tyre dimensions. Further, Wulfsohn and Upadhyaya (1992) provided an experimental technique for the determination of the dynamic 3-D contact profile. Lyasko (1994) verified the universal characteristics equation provided by Bidermahn (1963) for a given pneumatic tyre on a rigid surface. Sharma and Pandey (1996) studied the tyre deflection, contact area and ground pressure of three Indian tractor rear tyres viz., 11.2-28, 12.4-28 and 13.6-28 at normal loads ranging from 6.50 to 10.25 kN and inflation pressure ranging from 50 to 250 kPa on a hard surface. They reported that the modified universal characteristics equation of the tyre predicted deflection of all the three tyres tested within the ranges of load and inflation pressure used.

However, no literature is available on the behaviour of commonly used power tiller tyres on a rigid flat surface under various normal loads and inflation pressures. Keeping these factors in view, an investigation was undertaken with the following objectives :

1. To study the effect of normal load and inflation pressure on deflection and contact characteristics of a commonly used power tiller tyre.

2. To develop empirical models to predict the deflection and contact characteristics of a power tiller tyre.

Materials and Methods

A Kubota power tiller (6.7 kW at 2000 rpm rated speed) fitted with 6.00 x 12-4PR tyres was used for determining deflection and contact characteristics of a tyre. The total weight of the unballasted power tiller was 4.76 kN. The recommended inflation pressure of tyre by the manufacturer is 150 kPa and the pneumatic tyres had the pre-test use of 30 hours. Five levels of inflation pressure viz., 80, 100, 120, 160 and 200 kPa and six levels of normal load between 2.38 and 2.87 kN at 100 N interval were considered for the experiment keeping in mind the range of tyre inflation pressures and normal loads under field conditions during operation of the power tiller. A height gauge (0.002 cm least count) was used to measure deflection and a multiple overlay technique (Upadhyaya and Wulfsohn, 1990 and Sharma and Pandey, 1996) was followed to measure contact area of the tyre. A white paper was placed at the center of a steel plate and a blue carbon paper was placed on the paper. The carbon paper was covered with a drawing sheet and it was clamped tightly on the plate using steel flats at the periphery such that it was not displaced during the test. The power tiller with a given tyre inflation pressure was loaded to the required vertical load with dead weight (sand bags). The plate with the carbon paper covered with a drawing sheet was placed below each tyre of the power tiller. The imprint of the tyre on the white paper was obtained by applying entire weight of the power tiller with dead weight slowly on the tyres using a screw jack. The tyre was raised and rotated by few degrees to obtain a good imprint of the tyre on the white paper by overlaying a number of prints on the same area. During the test, brakes were applied on the axle while lowering the tyre to prevent the rolling of tyres. The entire static weight of power tiller on the tyres was ensured by carefully balancing the power tiller for 5-6 seconds on tyres. The outline of the contact area imprint was traced and the contact area was determined using a digital planimeter. The average contact area was determined by measuring the contact area of both the tyres with steel plate. Two replications were done.

Results and Discussion

Effect of normal load and inflation pressure on deflection and contact area of power tiller tyre

Variations in tyre deflection and contact area with inflation pressure at the range of normal loads considered during the experiment are presented in Figure 1. At a given inflation pressure, the tyre deflection increased as the normal load increased. This indicates a greater percentage of load supported by the tyre carcass as the normal load increased. However, deflection of the tyre decreased as the inflation pressure was increased at a constant normal load. This reflects the increase in the percentage of the normal load that was supported by inflation pressure, thereby decreasing the load that was supported by the tyre carcass. In general, contact area decreased as inflation pressure increased over the range of normal loads used and increased with normal load when inflation pressure was held constant.

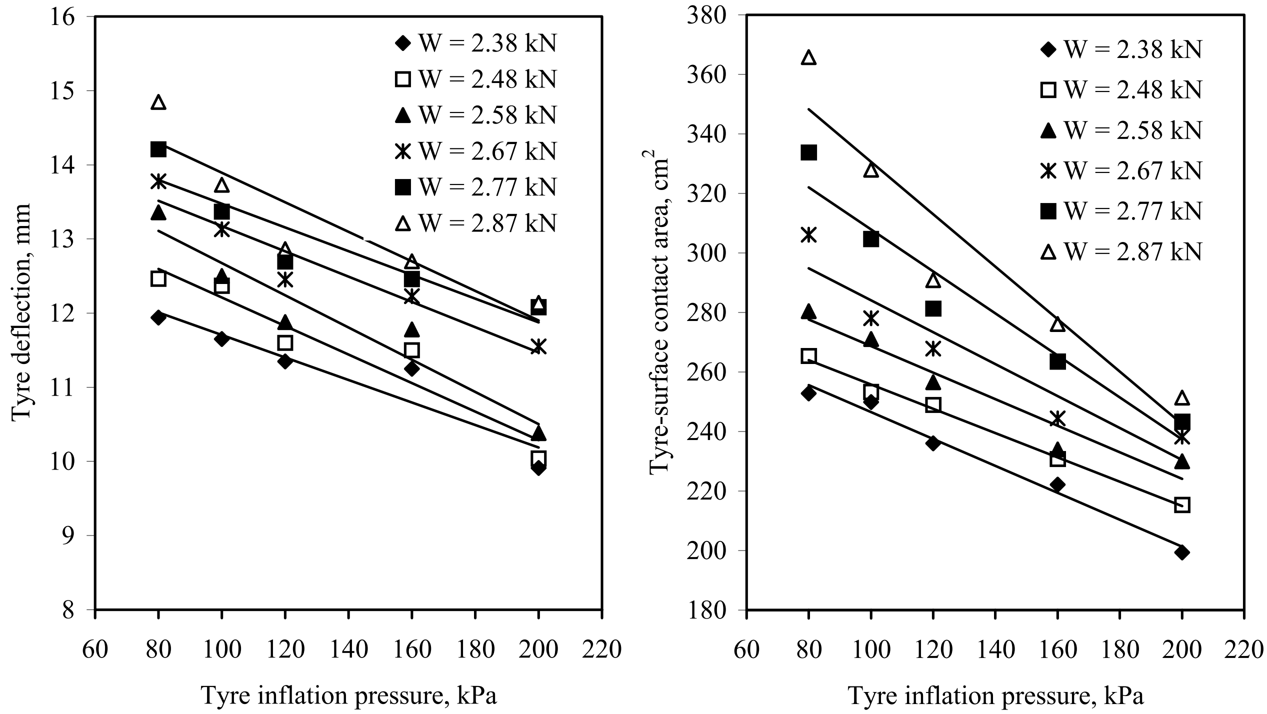


Figure 1. Variation in tyre deflection and contact area with inflation pressure at various normal loads

The data were subjected to an analysis of variance as shown in Table 1. Both inflation pressure and normal load significantly affected the deflection and contact area individually and their interactions at the 1 % level of significance.

Table 1 : ANOVA of deflection and contact area of power tiller tyre

Source of variation	Deflection				Contact area		
	df	SS	MS	F-value	SS	MS	F-value
Rep	1	0.02	0.02	7.14*	0.09	0.09	0.06 NS
p_i	4	39.57	9.89	3566.49**	38009.39	9502.35	6714.20**
W	5	32.22	6.44	2322.68**	35216.27	7043.26	4976.65**
p_i x W	20	2.94	0.15	53.06**	5000.88	250.05	176.68**
Error	29	0.08	0.0028		41.04	1.42	
Total	59	74.84			78267.66		

* Significant at 5 % level of significance ** Significant at 1 % level of significance
NS Non-significant

Further, the variation was linear as shown in Figure 1. Hence, the following linear regression model was considered to express the variation of deflection and contact area with inflation pressure at each normal load :

$$\delta = a + bp_i \quad ...(1)$$

$$A = c + dp_i \quad ...(2)$$

where, δ = deflection, mm

A = contact area, cm^2

p_i = inflation pressure, kPa

a, b, c and d are regression coefficients.

The values of regression coefficients along with t-values for linear variation of tyre deflection with inflation pressure at each normal load are presented in Table 2.

Table 2 : Regression coefficients, F-values and coefficients of determination of tyre deflection and contact area at various normal loads.

Normal load, kN	Tyre deflection (Eqn. 1)				Tyre-surface contact area (Eqn. 2)			
	Regression coefficient along with t-values in parenthesis		R^2	F	Regression coefficient along with t-values in parenthesis		R^2	F
	a	b			c	d		
2.38	13.23	-0.015 (-4.67)*	0.879	21.80*	291.75	-0.46 (-13.11)**	0.983	171.98**
2.48	14.14	-0.019 (-5.42)*	0.907	29.33*	296.66	-0.41 (-21.22)**	0.993	450.31**
2.58	14.85	-0.022 (-5.69)*	0.915	32.42*	313.24	-0.45 (-6.72)**	0.938	45.18**
2.67	14.88	-0.017 (-5.96)**	0.922	35.57**	337.81	-0.54 (-5.06)*	0.895	25.57*
2.77	15.08	-0.016 (-4.03)*	0.844	16.27*	378.60	-0.71 (-6.36)**	0.931	40.45**
2.87	15.89	-0.020 (-3.73)*	0.823	13.94*	418.73	-0.88 (-4.93)*	0.890	24.28*

* Significant at 5 % level of significance ** Significant at 1 % level of significance

NS Non-significant

It may be observed from Table 2 that the R^2 values are greater than or equal to 0.823 and the t-values are negative and significant. This indicates that tyre deflection and contact area significantly decreases linearly as inflation pressure increases at each value of normal load.

Figure 2 shows the contact pressure, called ground pressure in relation to inflation pressure at the range of normal loads considered for the experiment. The ground pressure is here assumed as the ratio between normal load on tyre and the contact area corresponding to the normal load. It is nearly linear to the inflation pressure and the inclination of the curves increased with the increase in normal load. The ground pressure was greater than the inflation pressure at low inflation pressure (80 kPa). This indicates that the tyre carcass contributes to the ground pressure at lower inflation pressure. However, when the inflation pressure was increased, the ground pressure was less than the inflation pressure at all normal loads.

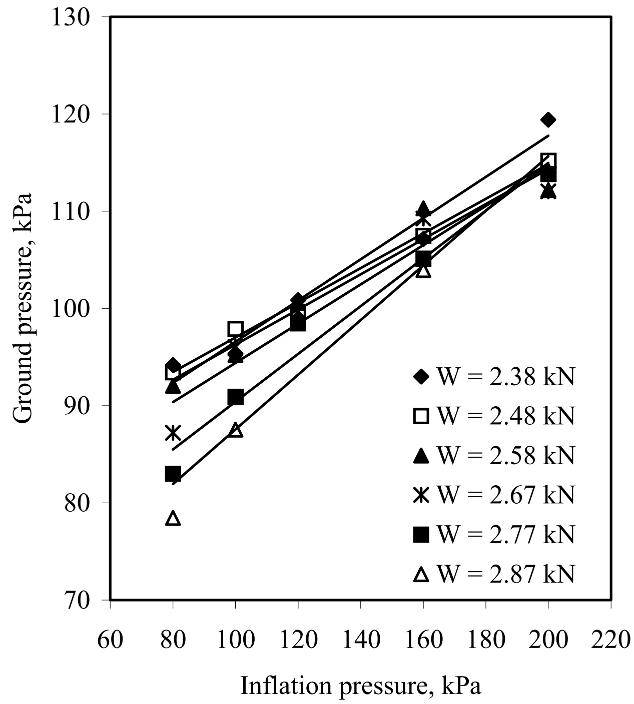


Figure 2. Variation in ground pressure with inflation pressure at various normal loads

Universal Characteristics of Tyre

The modified universal characteristics of a tyre (Sharma and Pandey, 1996) is given by :

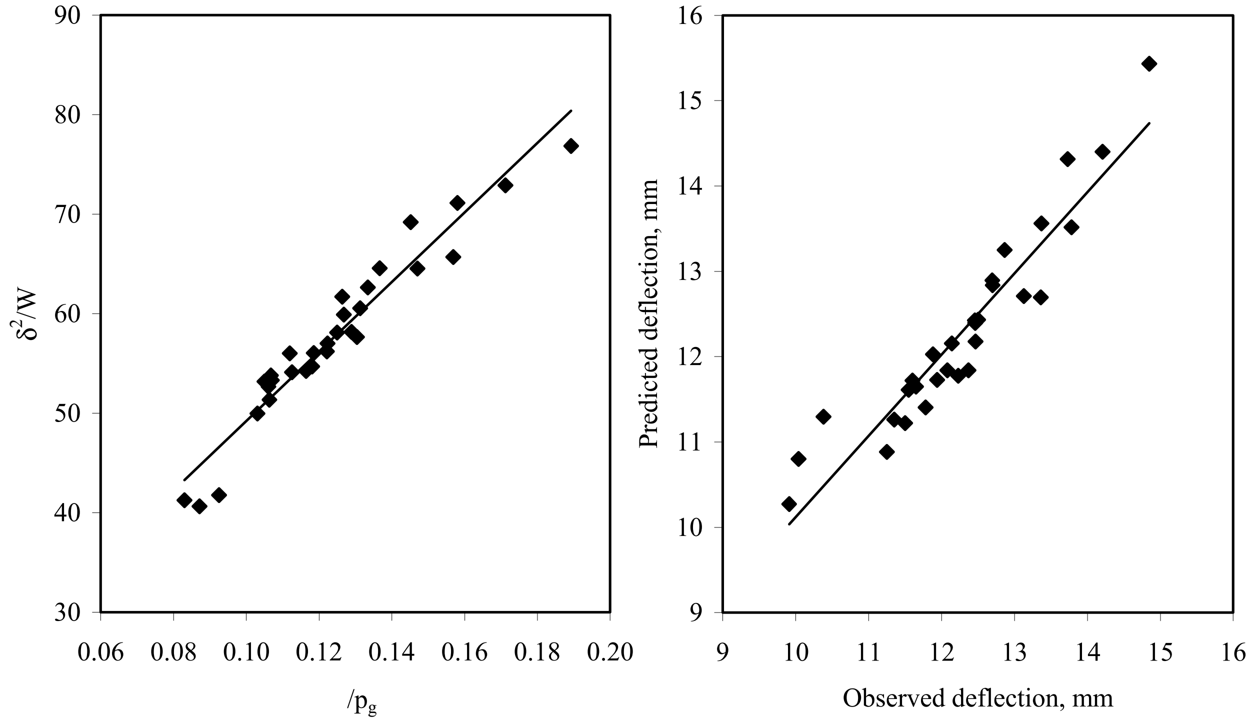
$$\frac{\delta^2}{W} = C_1 + C_2 \frac{\delta}{p_g} \qquad \ldots(3)$$

where, δ = deflection
W = normal load
p_g = average ground pressure
C_1 and C_2 are constants

The average ground pressure was calculated by dividing each value of normal load by contact area for each value of inflation pressure. Applying the model to the tyre under study, the universal characteristics of power tiller tyre can be represented as,

$$\frac{\delta^2}{W} = 14.319 + 349.044 \frac{\delta}{p_g} \qquad \ldots(4)$$

In this equation, deflection (δ), normal load (W) and ground pressure (p_g) are in mm, kN and kPa respectively. This equation has a t-value for slope = 19.860 indicating that $\frac{\delta^2}{W}$ increases linearly with $\frac{\delta}{p_g}$ as shown in 3(a). Further, the relationship is significant with R^2 = 0.933 reflecting the good fit of the equation (4) to represent the universal characteristics of a power tiller tyre. Figure 3(b) also shows that the model predicts the deflection values within acceptable limits (R^2 = 0.889) for the power tiller tyre within the range of normal load and inflation pressure of 2.38 to 2.87 kN and 80 to 200 kPa respectively.



(a) (b)

Figure 3. (a) Universal characteristics of power tiller tyre and (b) relationship between observed and predicted values of deflection

Thus, the result obtained through experiment and analysis coincided with the findings of Bidermahn (1963) and Sharma and Pandey (1996).

Conclusions

Based on the experiment conducted with the range of tyre inflation pressure (80-200 kPa) and normal load (2.38-2.87 kN), the following conclusions were drawn :

1. The tyre deflection linearly decreased with an increase in inflation pressure at constant normal load while it linearly increased with an increase in normal load at constant inflation pressure.

2. The contact area of the tyre with firm ground decreased linearly with an increase in inflation pressure at constant normal load and increased linearly with an increase in normal load at constant inflation pressure.

3. The empirical models for deflection and contact area express the behaviour of a power tiller tyre in the range of 2.38-2.87 kN normal loads and 80-200 kPa inflation pressure on a rigid flat surface.

4. The power tiller tyre considered for the study also follows the modified universal characteristics of a tyre in the range of 2.38-3.87 kN normal loads and 80-200 kPa inflation pressure on a rigid flat surface.

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