RESEARCH PAPER | International Journal of Agricultural Engineering | Volume 8 | Issue 2 | October, 2015 | 181-189
e ISSN–0976–7223 ■ Visit us : *www.researchjournal.co.in* ■ DOI: 10.15740/HAS/IJAE/8.2/181-189

Measurement of weight transfer in two wheel drive tractor by developed ring transducer

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Received : 08.06.2015; **Revised :** 15.08.2015; **Accepted :** 10.09.2015

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■ **ABSTRACT :** Weight transfer or weight shift is, in fact, reaction transfer or change in the reactions of front and rear wheels of the tractor. Weight transfer because of drawbar loading decreases soil reaction against the front wheels and increases reaction against the rear wheels. A study was done to measure the dynamic front wheel reaction of the tractor and thereby the weight transfer from front to the rear wheel. Developed ring transducer was attached below the tractor's front axle to measure the front wheel reaction. Field experiments were conducted using Ford-3630 tractor with three different implements *viz.*, 3-bottom mould board plough, 9-tyne cultivator and offset disc harrow. For each operation, the parameters such as dynamic front wheel reaction, draft, slip and depth were measured. The instrumented link forces were used to calculate implement draft. Slip was calculated by measuring actual speed in the field at different depths and theoretical speed on a concrete surface in the same gear and throttle position. The dynamic front wheel reaction was measured by using the developed ring transducer and thus, the weight transfer from front to rear was calculated. Also the weight transfer for a given draft was calculated theoretically and compared with the experimentally determined weight transfer. The data indicated that weight transfer increased with increase in draft. The maximum variation between theoretical and experimental values of weight transfer was found to be 12.62 per cent. This variation may be due to some assumptions made in theoretical calculation as well as due to vibration of the front axle while operating the tractor in the field.

■ **KEY WORDS :** Weight transfer, Dynamic front wheel reaction, Ring transducer, Draft, Slip

■ **HOW TO CITE THIS PAPER :** Patil, Mahesh R. (2015). Measurement of weight transfer in two wheel drive tractor by developed ring transducer. *Internat. J. Agric. Engg.*, **8**(2) : 181-189.

Weight transfer can cause a significant increase in the dynamic load on the drive tires, especially with mounted implements in high draft operations. During tillage operation with an implement attached to a 2-wheel drive tractor, proper distribution of weight to its front and rear wheels is a pre-requisite for a good design. Any improper distribution of weight to the front and/or rear wheels due to dynamic weight transfer may lead to the loss of stability as well as reduction of traction performance. Farm tractor accidents are estimated to claim many lives annually throughout the world. Of these fatalities approximately 70 per cent are caused by the tractor either overturning sideways or rearward. Rearward overturnings take place when dynamic front wheel reaction becomes zero; hence, there is a need to measure the dynamic front wheel reaction so that tractor operator can have in advance idea of the overturn (Lehtola *et al.*, 1994). Modeling is one of the most commonly used methods in the extensive study of tractor dynamics, performance and overturns.

Many mathematical models have been developed previously for given conditions or certain prototype tractors (Larson and Liljedahl, 1971; Davis and Rehkugler, 1974; Feng and Rehkugler, 1986; Pacey and Walker, 1996) and Larson *et al*. (1976) developed a mathematical model of tractor dynamics in three dimensions to predict the general three-dimensional motion of single-front-wheel row crop farm tractors. Rehkugler *et al*. (1976) and Tamny (1993) applied simulation and theoretical methods to study tractor overturns and roll stability, respectively. Murphy and Johnson (1982) analyzed the reasons for tractor overturn, and indicated that the interactions between tractor operator, tractor and environment are major reasons leading to an overturn accident. They described a stability indicator device mounted on the tractor in their approach to the rollover problem and the mathematical basis for stability.

Spencer and Gilfillan (1976 and 1978); Spencer and Owen (1981) and Spencer *et al.* (1985) studied a method of tractor stability assessment, discussed the field measurement of control loss limits, performed a tilt test and developed a field technique whereby the static stability limit of a machine can be measured without recourse to overturn trials or complex computation. They examined the developed theoretical model of wheel-ground normal reaction.

Numerous safety controls have been developed for tractors, but none of them effectively prevent rearward overturns (Murphy *et al.*, 1985 and Smith and Liljedhal, 1972). All controls for the prevention of rearward overturns have been angle measuring devices which either signal the driver or shut the engine off when a condition of static instability reaches. Rollover protective structures (ROPS) can prevent drivers from being crushed when a tractor rolls over but still during the accident, both driver and tractor get damaged.

One of the problems with overturns is that the operator does not have a clear indication under which conditions it is about to happen. In other words, there is no direct method that tells the operator how close he got to overturning. To prevent the tractor rearward overturn, there must be sufficient weight on the tractor front axle always. When tractor travels on any ground, the load on the front axle of tractor must be 20 per cent minimum of the total weight of the tractor. Hence, there is a need to measure front wheel reaction in the dynamic condition and to know whether the weight coming on the tractor front axle is sufficient from stability point of view.

METHODOLOGY

Ring transducer :

A ring transducer was developed for measuring the front wheel reaction of tractor at Department of Agricultural and Food Engineering, IIT Kharagpur (Patil and Shinde, 2015). Linearity of the transducer bridge output voltage with the load on front axle justifies the suitability of the transducer for the purpose of present work. As the transducer consists of only four strain gauges which can be easily affixed at the specific location on the ring, it becomes simple, easy to install, low in cost and reliable transducer. It occupies a little space below the front axle of tractor as shown in Fig. A and doesn't hinder the normal working of tractor. The excitation voltage used for the bridge was 10V.

Fig. A : Attachment of ring transducer to the front axle of tractor

Dynamic force analysis of tractor - mounted implement combination :

The mechanics of tractor-implement system was studied for a tractor operating on a leveled ground. After analyzing the forces in horizontal and vertical directions, the final equations were formulated to calculate reaction against front and rear wheels and finally the theoretical

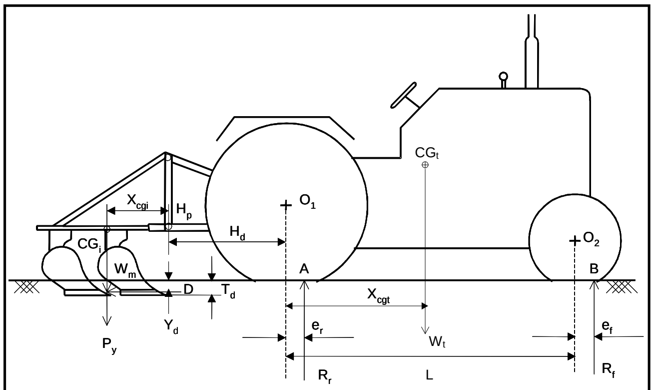

Fig. B : Free body diagram of tractor-implement combination

weight transfer from front to rear. Fig. B shows the side view of tractor- mould board plough combination. The analysis will remain same for other mounted implements like cultivator, disk harrow etc. Following major assumptions were made.

- Center of gravity of tractor is located without operator.
- Angular motion of wheel of tractor is ignored.
- Implement is operating at uniform depth.
- The sinkage and deflection of the tyres are reasonably small as compared to the rolling radii of the tyres and hence, neglected.
- The center of gravity and center of resistance of implement are assumed to be acting in the same vertical plane.
- Vertical soil reaction is 0.3 times the horizontal soil reaction.
- The two lower links are of equal length and coincide together when viewed from the side *i.e.,* two lower hitch points lie at the same height above the ground level.
- Centre of resistance is located at a distance of two-third of depth of operation from ground surface.

Taking moment of forces about point 'B', the dynamic weight on tractor rear axle was calculated as follows:

$$R_r\,(L - e_r + e_f) - W_t\,(L + e_f - X_{cgt}) - (W_m + P_y)\,(X_{cgi} + H_d + L + e_f) + DY_d = 0 \text{ or,}$$

$$R_r = \frac{W_t(L + e_f - X_{cgt}) + (W_m + P_y)(X_{cgi} + H_d + L + e_f) - DY_d}{L - e_r + e_f}$$

Also, $R_f + R_r = w_t + w_m + P_y$ **or,** $R_f = (W_t + W_m + P_y) - R_r$

Weight transfer from front end of the tractor is given by,

$$WTF = FWS - R_f$$

Weight transfer from implement side is given by,

$$WTI = R_r - RWS - WTF$$

where, R_r= rear wheel dynamic weight; R_f= front wheel dynamic weight; *RWS* = rear wheel static weight; *FWS* = front wheel static weight; W_t = weight of tractor acting at CG_t; W_m = weight of implement acting at CG_i; X_{cgi} = horizontal distance of CG of implement from tractor lower hitch point H_p; H_d = horizontal distance of tractor lower hitch point from the rear axle center; L = wheel base; D = draft; P_y = vertical component of soil force and was assumed 0.3 times the draft; X_{cgt} = horizontal distance of CG of tractor from the rear axle center; $Y_d = \frac{2}{3}T_d$ depth at which draft acted (assumed); T_d = depth of operation; e_r = rear wheel eccentricity = $\rho_r\, r_r$ (Liljedahl *et al*., 1989); r_r = rolling radius of the rear wheel of tractor; e_f = front wheel eccentricity = $\rho_f\, r_f$ (Liljedahl *et al.*, 1989); r_f = rolling radius of the front wheel of tractor; ρ_r = co-efficient of rolling resistance of the rear wheel of tractor; ρ_f = co-efficient of rolling resistance of the front wheel of tractor.

The main aim of carrying out field tests was to measure the draft for different tillage implements like M.B. plough, cultivator and offset disc harrow and corresponding front wheel reaction (front wheel reaction was measured from ring transducer output voltage which was already calibrated in the laboratory). A Ford-3630, 2WD tractor (33.8 kW maximum PTO power) with three different implements was used for the field experiments.

Draft measurement :

The draft requirement of an implement was measured by an instrumented three-point linkage of tractor as shown in Fig. C. The electrical strain gages of resistance 350 Ω and 2.6 gage factor were mounted on the body of both lower links to measure the tensile and bending forces. A fabricated proving ring attached to the top link was used to measure the compressive force acting on the link during operations.

Recording unit :

The outputs of all Wheatstone bridges, potentiometer circuits were stored in Spider-8 data acquisition system (DAS). It was powered with 12V DC battery of the tractor.

Fig. C : Instrumented three point linkage (1. Top link; 2. Lower link)

Field testing of ring transducer :

All field experiments were conducted on barren land of Research farm of the Department of Agricultural and Food Engineering, IIT Kharagpur. A Ford-3630 tractor with different implements was used for field operation.

Field preparation :

A barren land of approximately 2.5 ha was chosen for field testing, and it was divided into 50 m x 25 m sub plots. These sub plots were used for measuring the draft of tillage implements and corresponding front wheel reaction of the tractor at different depths for each implement.

Measurement of speed of operation :

The time taken to travel 25 m distance was measured with a mechanical stopwatch and the speed of operation was calculated by,

$$V_a = 3.6 \times \frac{25}{t}$$

where, V_a = speed of operation, km/h; t = time, s

Measurement of wheel slip :

The measurement of slip was based on the fixed number of rear wheel revolution. The distance covered in ten rear wheel revolutions was noted with and without load and the values were used to calculate slip by using following expression :

$$\text{Slip}(\%) = \frac{m_0 - m}{m_0}$$

where, m_0 = distance travelled for ten number of revolutions with zero pull; m = distance travelled for ten number of revolutions with pull.

Depth of operation :

Depth of operation (distance between furrow sole and ground level) was measured with a scale along the furrow wall at an interval of about 3 m along the length of the furrow. The average of five readings was calculated to determine the depth of operation of a tillage implement.

Test procedure :

Before each test, the soil data (cone index and moisture content) were collected and the null adjustments of the Wheatstone bridges were made keeping the tractor and implement on a level ground.

Ring transducer was attached to the front axle by lifting the front end of the tractor by hydraulic jack and transducer output voltage was set to zero. The initial readings of each potentiometer circuit channel were noted down.

During test run of 25m, the variables recorded were voltage output against tensile force and bending force experienced by the lower links and compressive force by top link, angles made by the links and output voltage of the developed ring transducer for measuring dynamic front wheel reaction of the tractor. All the data were set at a frequency of 50 Hz in each channel of DAS. Each test was replicated twice for each depth of operation.

The distance covered for 10 revolutions of the drive wheel of the tractor without engaging the implement into the soil was measured at particular throttle and gear settings on hard soil condition. After engaging the implement into the soil, tractor was operated at same throttle and gear settings throughout the test run. The distance travelled and time taken for 10 revolutions of driving wheel for each case was measured to calculate the slip of driving wheel and speed of operation of the tractor.

Care was taken to maintain the tire inflation pressure

(1.1 kg/cm^2 for rear wheel and 1.9 kg/cm^2 for front wheel) constant for all the tillage operations.

Similar procedure was followed for all the implements at each depth of operation.

RESULTS AND DISCUSSION

Field experiments were carried out using different tillage implements to determine the dynamic front wheel reaction, draft of implement and wheel slip of a 2 WD tractor. The results obtained from field experiments are presented below.

Tractor with mould board (MB) plough :

The tractor was operated with a 3 bottom MB plough at 15, 20 and 25 cm depth of operation on hard soil with average cone index of 1428 kPa. The average wheel slip observed was 27.83, 31.56 and 37.92 per cent for 15, 20 and 25 cm depths of operation, respectively. The draft varied from 1000 kg to 1565 kg with increase in depth from 15 to 25 cm. The comparison between experimental *i.e.*, determined by measuring dynamic front wheel reaction with the developed transducer and theoretical values of weight transfer is shown in Figs. 1 to 3 in the Annexure. The

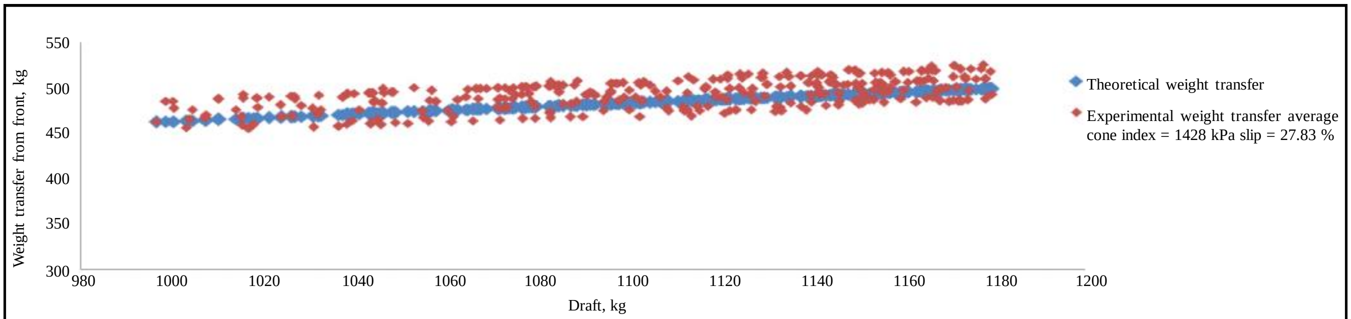

Fig. 1 : Comparison between experimental and theoretical weight transfer for ploughing operation at 15 cm depth

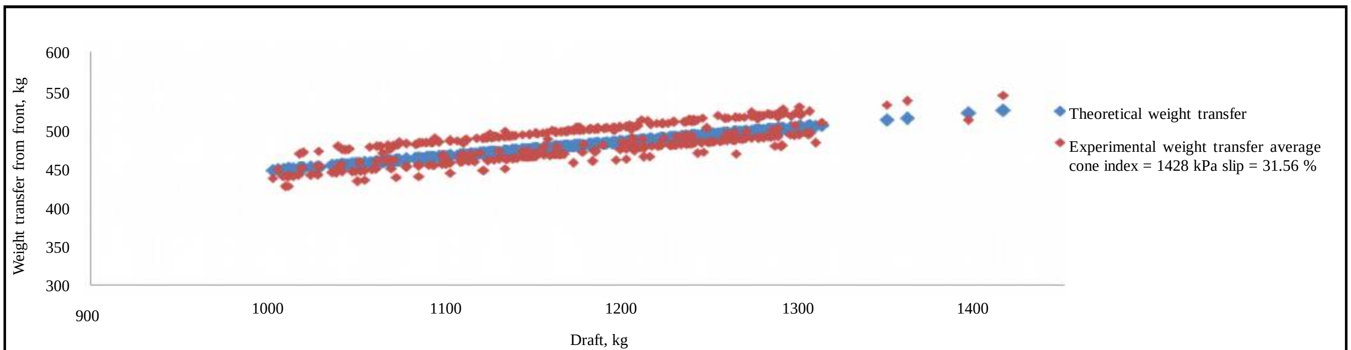

Fig. 2 : Comparison between experimental and theoretical weight transfer for ploughing operation at 20 cm depth

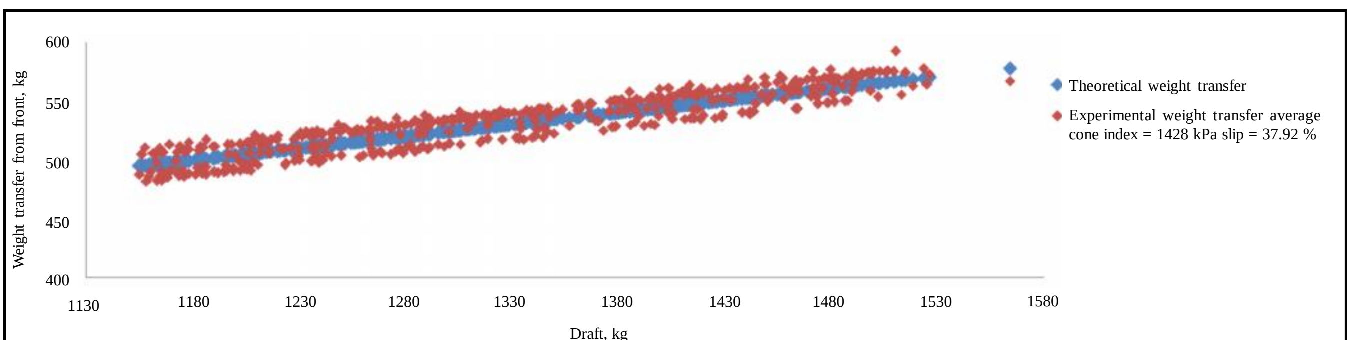

Fig. 3 : Comparison between experimental and theoretical weight transfer for ploughing operation at 25 cm depth

data indicated that as draft increased, weight transfer also increased. The deviation of actual weight transfer with theoretically calculated values was -5.83 to 5.20 per cent for MB plough. This variation may be due to

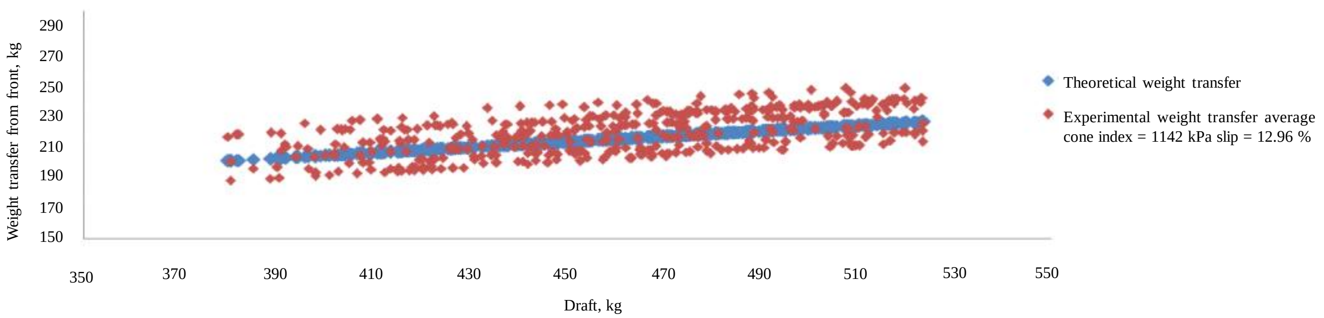

Fig. 4 : Comparison between experimental and theoretical weight transfer for tilling operation at 8 cm depth

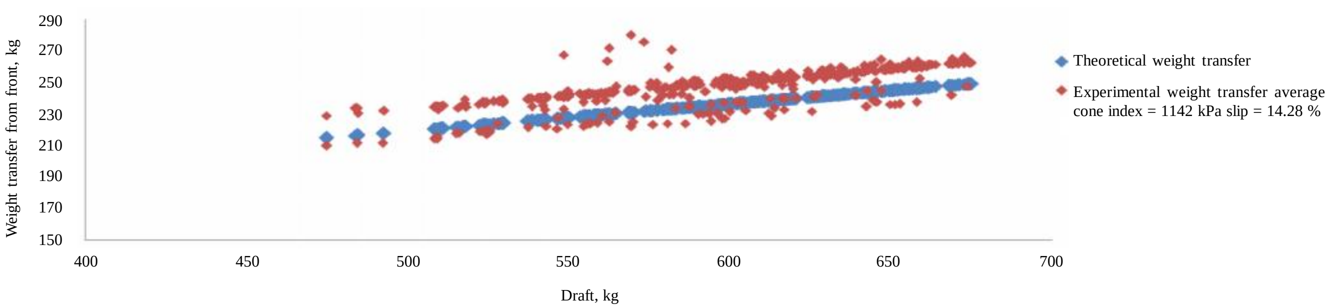

Fig. 5 : Comparison between experimental and theoretical weight transfer for tilling operation at 10 cm depth

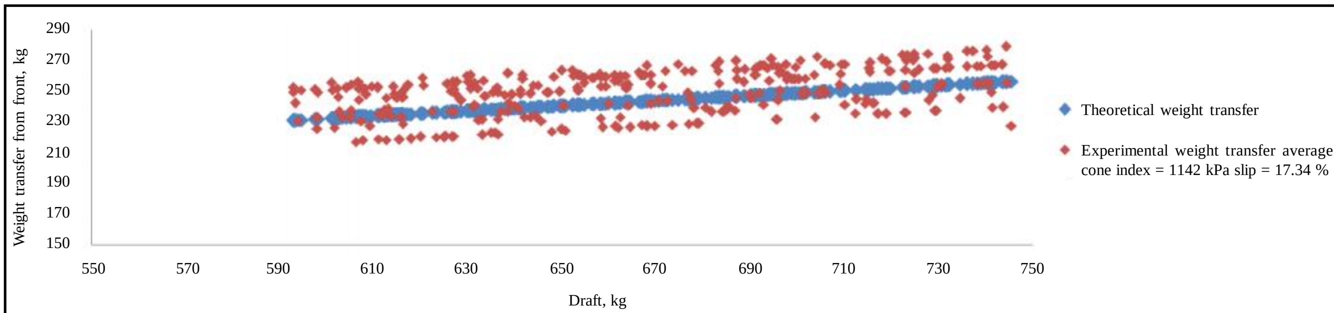

Fig. 6 : Comparison between experimental and theoretical weight transfer for tilling operation at 12 cm depth

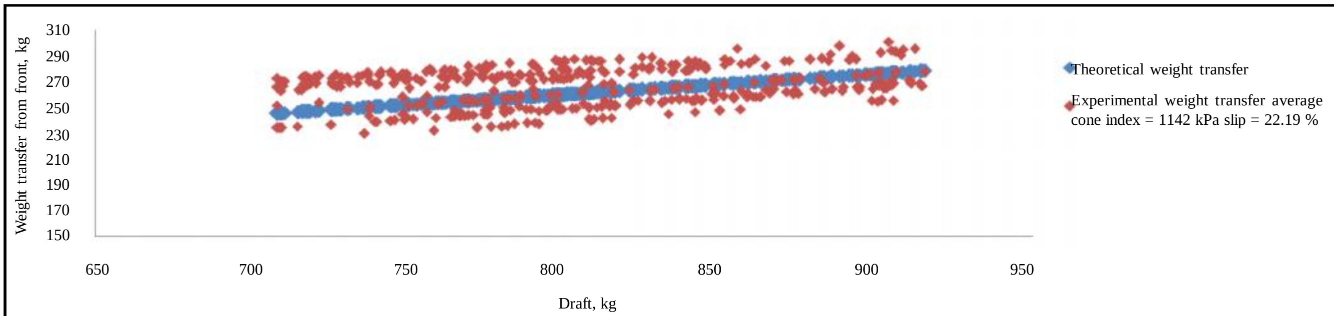

Fig. 7 : Comparison between experimental and theoretical weight transfer for tilling operation at 14 cm depth

some assumptions made in theoretical calculation as well as due to vibration of the front axle while operating the tractor in the field.

Tractor with 9-tyne cultivator :

Field experiments were conducted with a 9-tyne cultivator at 8, 10, 12 and 14 cm depths of operation on

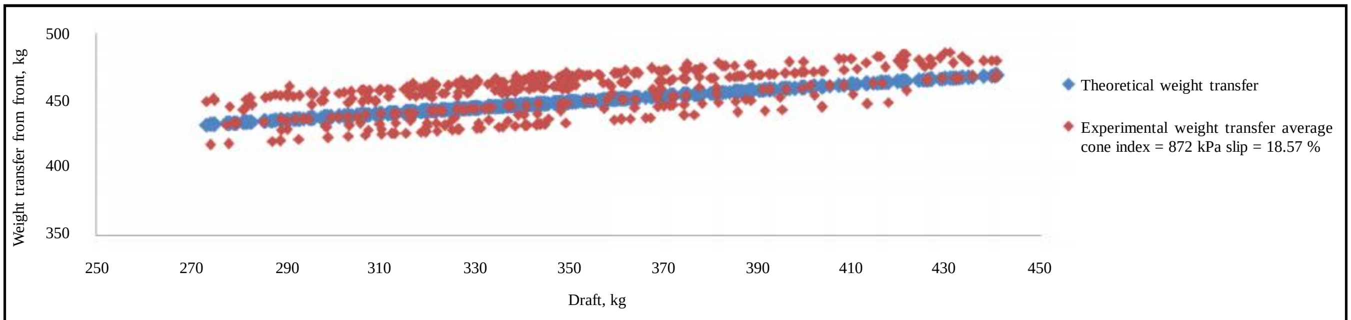

Fig. 8 : Comparison between experimental and theoretical weight transfer for harrowing operation at 8 cm depth

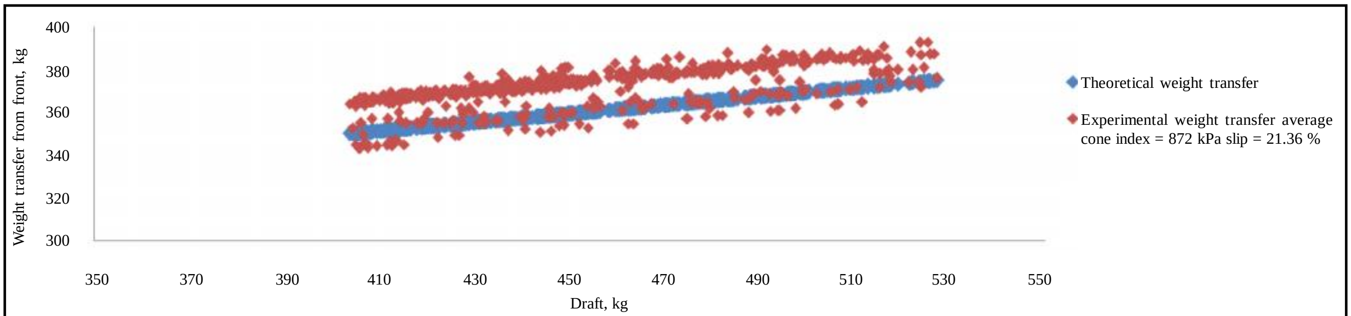

Fig. 9 : Comparison between experimental and theoretical weight transfer for harrowing operation at 10 cm depth

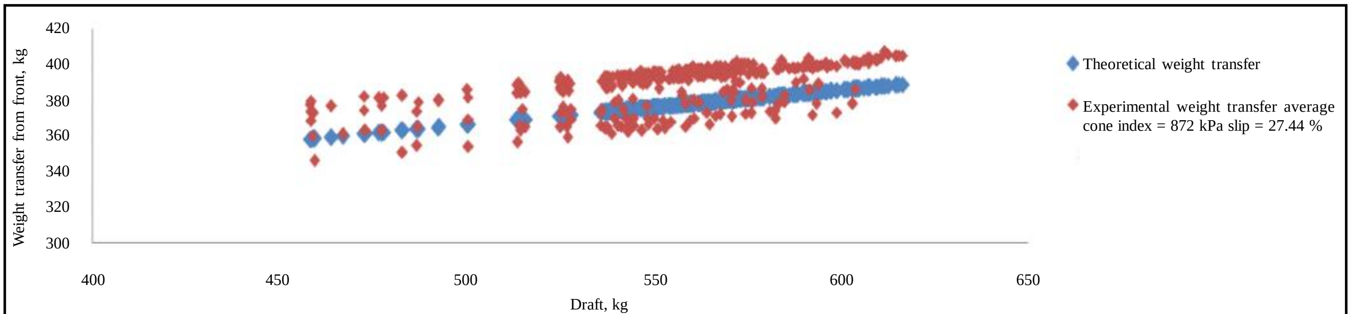

Fig. 10 : Comparison between experimental and theoretical weight transfer for harrowing operation at 12 cm depth

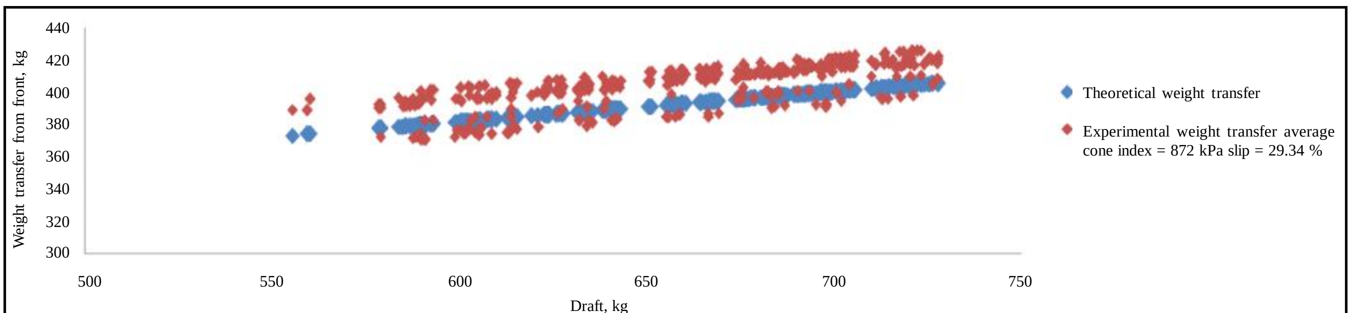

Fig. 11 : Comparison between experimental and theoretical weight transfer for harrowing operation at 14 cm depth

medium soil with average cone index of 1142 kPa. The average wheel slip observed was 12.96, 14.28, 17.34 and 22.19 per cent for 8, 10, 12 and 14 cm depths of operation, respectively. The draft varied from 385 kg to 920 kg with increase in depth from 8 to 14 cm. The comparison between experimental *i.e.*, determined by measuring dynamic front wheel reaction with the developed transducer and theoretical values of weight transfer is shown in Fig. 4 to 7 in the Annexure. It is clear from the graphs that as draft increased, weight transfer also increased. The data indicated that the variation between actual weight transfer and theoretically calculated weight transfer was -12.62 to 10.49 per cent. This variation may be due to some assumptions made in theoretical calculation as well as due to vibration of the front axle while operating the tractor in the field.

Tractor with offset disc harrow :

The tractor was also operated with an offset type disc harrow at 8, 10, 12 and 14 cm depths of operation on tilled soil with average cone index of 872 kPa. The average wheel slip observed was 18.57, 21.36, 27.44 and 29.34 per cent for 8, 10, 12 and 14 cm depths of operation, respectively. The draft varied from 390 kg to 725 kg with increase in depth from 8 to 14 cm.

The comparison between experimental *i.e.*, determined by measuring dynamic front wheel reaction with the developed transducer and theoretical values of weight transfer is shown in Figs. 8 to 11 in the Annexure. It is clear from the graphs that as draft increased, weight transfer also increased. The data indicated that the deviation of actual weight transfer was -5.07 to 7.69 per cent when compared with theoretically calculated weight transfer. This variation may be due to some assumptions made in theoretical calculation as well as due to vibration of the front axle while operating the tractor in the field.

Among all the three operations, the maximum weight transfer occured when tractor was operated with MB plough because of maximum draft.

Conclusion :

Based on the results obtained in this study, the following conclusions were drawn:

– The developed ring transducer can be mounted on any tractor below the front axle to measure the dynamic front wheel reaction and thereby weight transfer from front axle to rear axle.

– The maximum weight transfer was observed during ploughing operation followed by harrowing and tilling operation.

– The maximum range of variation between measured and theoretically calculated weight transfer for field experiments was found to be -12.62 to 10.49 per cent.

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