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# Determination of he-buffalo leg sinkage through simulation in laboratory and field condition to assess reaction under the hooves

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ABSTRACT

In spite of increasing mechanization of agricultural operations, animals remain an important source of energy for crop production in India. It is easily available source of farm power, especially in hilly regions of the state of Uttarakhand, where the land is fragmented, irregular, scattered in the form of bench terraces and not suitable for mechanization. He-buffalos are not only used for seedbed preparation but are major source for carting the cane to sugar mills in Tarai region of this state. Different types of animal develop power differently. A good amount of work has been done on various aspects of draught animal power especially on work rest cycle in linear and rotary mode of operation but very little work has been done on how they actually produce tractive force. With this aim a study was conducted in the University to determine the he-buffalo leg sinkage through simulated wooden leg and also to assess vertical reactive force under the feet of he-buffalo under laboratory and field condition. On the basis of the study it was concluded that the animal leg sinkage increased or decreased significantly with the change in soil moisture content, soil hardness (cone index value) and magnitude of load applied. It was also observed that sinkage of the front legs of he-buffalo was more than the rear legs. Similarly the reactive force was found greater on the front legs than rear legs up to a load equivalent to 26.8% of body weight. Exceeding this load the reactive force was observed more on rear legs compared to front legs probably due to weight transfer phenomenon.

**Key words**: Hoof area, Leg sinkage, Pull, Reactive force under hoof, Traction

Animal traction has a long history in agricultural production. It is an appropriate, affordable and sustainable power source available at the door step of the farmer. More than 2 billion people, around the world, depend on the draught animal power for ploughing and other operations including transport. It is estimated that there are 35 million animal drawn vehicles in the word and India alone has about 43% of them (FAO 2001). There are various types of draught animals that are used for farm operations in different-regions of the country.The reasons for the continuing importance of draught animals is the decrease in the size of land holdings, limitation of tractor to meet all the requirements of crop production and the need to have readily available draught power at village level during the peak season of agricultural operations. Approximately 95% area of Uttarakhand state, that includes Garhwal and Kumaon hill divisions has a diversified range of altitudinal variation (Sharma 2006). Most of the farm lands are scattered under bench terraces and valleys. The majority of hill population is living below the poverty line. The farmers are still using due to economic constraints, traditional animal drawn wooden tool and equipment leading to output of very poor quality. Therefore it is necessary to provide them with new tools and equipment for better quality of work. Also equipment should match pulling capacity of animals owned by them. The animal's capacity for carrying out a particular work depends upon the draught force and forward speed. Both the speed and force of an animal it exerts, vary as the animal walks (Devnani 1982). Since vertical load is important in determining the amount of horizontal force that can be generated at the ground contact area, therefore greater the load on limb of animals greater the thrust it is capable of producing before slippage occurs (Bansal and Thiertein 1986). Ortiz (2007) stated that while pulling a load, weight transfer from front limbs to the rear limbs may take place that would help the rear limbs in producing higher magnitude of traction.

In view of the very limited work available on animal traction in Indian scenario, an effort was made to develop a theory for prediction of vertical reactive force under the front

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and rear foot of the animal while in motion. The present study was conducted on he-buffalo under controlled conditions as well as in field condition.

## MATERIALS AND METHODS

*Linear soil bin and artificial wooden legs:* A linear soil bin (Fig. 1) of length, width and height 2,400 mm×1,000 mm×1,000 mm was used to conduct the experiment in the laboratory. The soil bin has a trolley which has provisions for manipulating and leveling the soil of the bin. The bin was filled with locally available slity-clay-loam soil, for the experiment, up to a depth of 600mm. The test set-up, used for the pressure and sinkage test, consists of a MS square


Figs 1–2. **1.** Soil bin with test set-up for pressure and sinkage study **2.** Artificial wooden legs used in soil bin experiment.

frame of size 600 mm × 600 mm, a hydraulic jack, electronic load cell and simulated wooden leg of he-buffalo. A scale is provided for measuring the depth of sinkage. The hydraulic jack had a lift capacity of 19600N with total linear displacement of the ram as 0–200 mm. Artificial wooden he-buffalo legs (Fig. 2) were fabricated having hoof area 12,000 mm² (small size he buffalo with 300 kg body weight), 13,000 mm² (medium size of he-buffalo with 400 kg body weight), and 14,000 mm² (heavy and very heavy size of he-buffalo having 500 kg and 600 kg body weight) as suggested by Singh *et al*. (2009).

*Field experiment:* A he-buffalo, body weight 600 kg and hoof area of 14,200 mm$^2$ was selected to study the leg sinkage in actual field condition at different levels of soil moisture content, soil hardness and load applied. A portable loading device (friction type dynamometer) was used for loading the he-buffalo during the experiment *in-situ* condition.

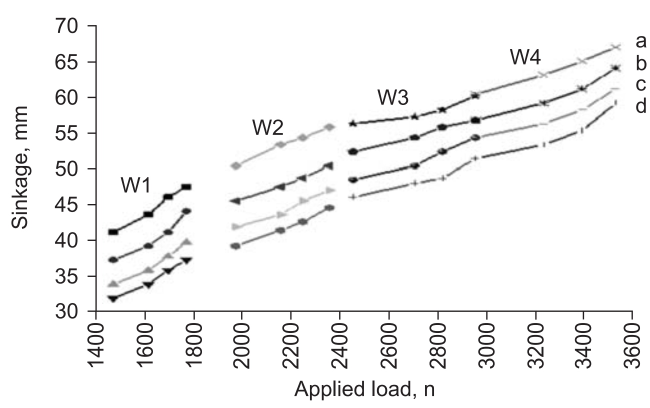
*Experimental parameter:* The experiments were conducted in laboratory at 4 levels of soil moisture contents ranging from 22 to 24, 18 to 20, 13 to 15 and 8 to 10%, 4 levels of soil hardness (0.040, 0.047, 0.052 and 0.062 N/mm$^2$), four levels animal body weight (300 kg, 400 kg, 500 kg and 600 kg) and 4 levels of pull force (0, 10, 15 and 20% of the animal body weight). For each of these variables depth of leg sinkage was measured. The experiment was laid down in factorial design with 4 replications of each treatment.

## RESULTS AND DISCUSSION

*Effect of soil moisture content on sinkage:* The relation between load applied and leg sinkage at different soil moisture content are presented in Figs 3 and 4. The results revealed that the hoof sinkage increased with the increase in moisture content. The sinkage was observed less for soil having lesser moisture content but as the moisture content of soil increased the leg sinkage also increased for all the values of load applied. The reason for more leg sinkage at higher soil moisture content may be due to less load bearing capacity of the soil.

*Effect of soil hardness on sinkage:* The leg sinkage was also observed at 4 levels of soil hardness having cone index values of 0.040 N/mm$^2$, 0.047 N/mm$^2$, 0.052 N/mm$^2$ and 0.062 N/mm$^2$, respectively, and the relationship are shown in Figs 3 and 4. The relationship showed that the leg sinkage decreased with the increase in soil hardness for all the levels of soil moisture content and load applied. The leg sinkage was observed to be more for less compact soil. The reason for less sinkage at highly compacted soil, at a particular level of soil moisture content, may be due to the fact that the compacted soil offers more resistance to penetration resulting in lesser sinkage and vice-versa.

*Effect of load on sinkage:* In the laboratory experiment, 4 levels of loads equivalent to a pull force of 0, 10, 15 and 20% of he-buffalo body weight were applied and data regarding legs sinkage was recorded. The relationship (Figs 3, 4) between load applied and leg sinkage showed that as the load applied increases, the depth of sinkage also increases, for a particular level of soil moisture content and soil hardness which is obvious. However, the rate of increment for depth of sinkage was found not in the same proportion in which the loads were applied. The data were statistically analyzed and the result showed that all the levels of soil moisture content, soil hardness and applied load have significant effect on simulated leg sinkage. The interaction terms of these




(W1,W2,W3, W4- levels of body weight; a, b, c, d- levels of soil hardness)

Fig. 3. Effect of load on sinkage of wooden leg for different size of animals, soil hardness at 8–10% soil moisture content.

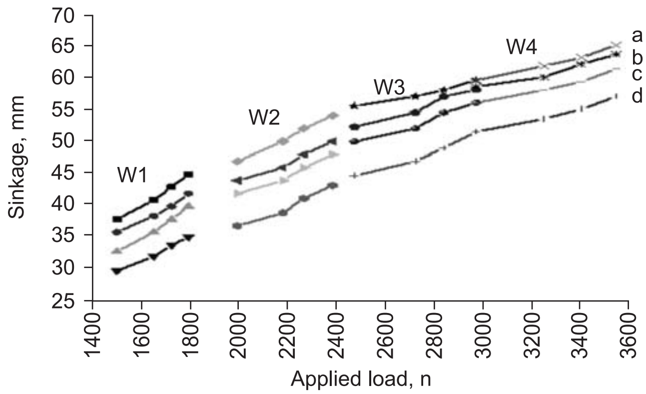



Fig. 4. Effect of load on sinkage of wooden leg for different size of animals, soil hardness at 22–24% soil moisture content.

parameters were also found to have significant effect on sinkage depth.

*Effect of pressure on sinkage:* In this study 3 sizes of wooden legs were manufactured having different hoof size representing the hoof of four sizes of he-buffalo (based on body weight) namely light weight, medium, heavy and very heavy weight. The pressure under each size of hoof was determined and the results are presented in Figs 5 and 6. The trend showed that the pressure required to press the he-buffalo hoof into the soil increased non-linearly. At lesser pressure the depth of sinkage was found less but as the pressure increased, due to large load applied on simulated leg, the sinkage also increased. It is clear from the data that for a particular value of soil moisture content and cone index value, the depth of sinkage was observed to increase with increase in pressure under hoof. However, its value was found less when soil with different cone index and same moisture content was compared.

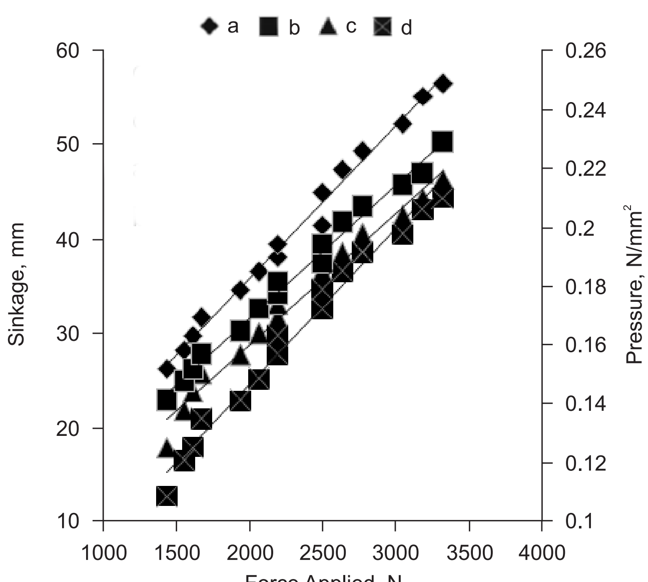



Fig. 5. Force, pressure and sinkage relation-ship for silt clay loam soil at 8–10% moisture content.

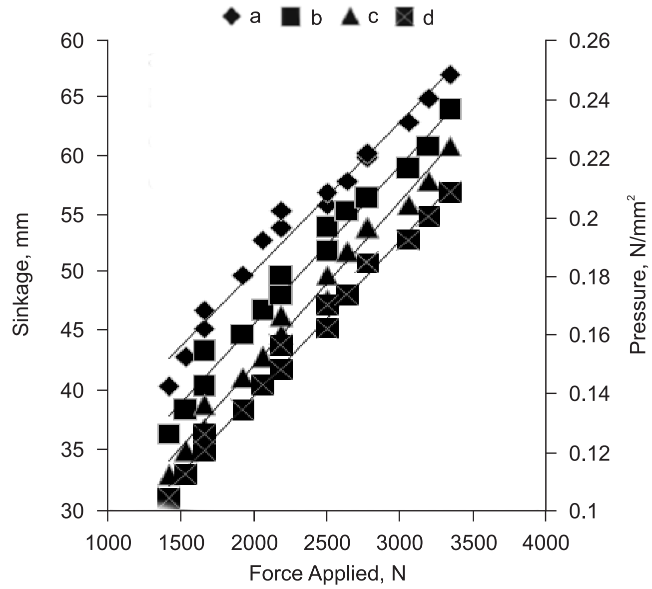



Fig. 6. Force, pressure and sinkage relationship for silt clay loam soil at 22–24% moisture content.

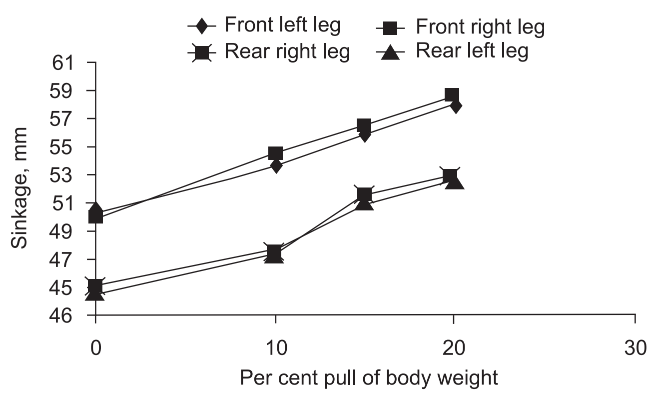



Fig. 7. Relationship between pull (% body weight) and sinkage of individual legs at 8–10% moisture content and 0.040N/mm$^2$ cone index.

This trend was observed for all the levels of moisture content and cone index value included in the study. On the basis of the result obtained it is clear that the depth of sinkage increased with the increase in pressure and vice-versa.

*Mathematical model:* Utilizing the laboratory test data and multiple regression analysis a mathematical model was developed to determine the effect of soil moisture content, cone index, animal weight and load applied on sinkage of simulated wooden leg. The result of multiple regression analysis showed that a linear relation existed between the depth of sinkage and other independent parameters as mentioned above. A generalized linear equation was developed, which is of the following form:

$$Z = k_0 + k_1 M + k_2 C + k_3 A + k_4 W \quad \text{.... (1)}$$

$$Z = 17.23 + 1.00 M + 43.93 C + 0.000316 A + 0.0122 W$$

where, Z, sinkage (mm); M, soil moisture content (%); C, soil cone index (kg/cm$^2$), A, animal weight (kg); W, load applied (N); $k_0$, $k_1$, $k_2$, $k_3$, $k_4$, regression coefficients.

Table 1. Average sinkage of he-buffalo of body weight 600 kg with hoof area of legs 14,200 mm$^2$ in field observation

| Range of soil moisture content (%) | Cone index (N/mm$^2$) | Pull equivalent to body weight (%) | Sinkage, (mm) | | | | Range of soil moisture content (%) | Cone index (N/mm$^2$) | Pull equivalent to body weight (%) | Sinkage, (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Front legs | | Rear legs | | | | | Front legs | | Rear legs | |
| | | | Left leg | Right leg | Left leg | Right leg | | | | Left leg | Right leg | Left leg | Right leg |
| 8–10 | 0.040 | 0 | 50.3 | 50 | 44.8 | 45 | 18–20 | 0.040 | 0 | 58 | 57.8 | 53.3 | 53 |
| | | 10 | 53.8 | 54.5 | 47.5 | 47.8 | | | 10 | 60.8 | 59.8 | 56 | 56 |
| | | 15 | 56 | 56.5 | 51 | 51.5 | | | 15 | 62 | 61.3 | 57.5 | 57.3 |
| | | 20 | 58 | 58.5 | 52.8 | 53 | | | 20 | 65 | 65 | 60 | 60.5 |
| | 0.047 | 0 | 43.5 | 44 | 39 | 39 | | 0.047 | 0 | 56.5 | 56.8 | 51 | 51.3 |
| | | 10 | 46 | 46.5 | 41.5 | 41.8 | | | 10 | 58.5 | 59 | 53 | 53.5 |
| | | 15 | 48.8 | 49.3 | 44 | 45 | | | 15 | 61 | 60.8 | 55 | 55.3 |
| | | 20 | 50.8 | 50.8 | 45.8 | 45.8 | | | 20 | 63 | 62.8 | 58 | 57.5 |
| | 0.054 | 0 | 40 | 40 | 35.5 | 36 | | 0.054 | 0 | 54.8 | 54.8 | 49.5 | 50 |
| | | 10 | 44 | 44.5 | 39 | 39 | | | 10 | 57.3 | 57.5 | 51.5 | 51 |
| | | 15 | 47 | 44 | 41 | 41.5 | | | 15 | 58 | 58 | 51.5 | 53.5 |
| | | 20 | 49 | 49.5 | 42.5 | 42.5 | | | 20 | 60 | 60 | 56 | 56 |
| | 0.064 | 0 | 38.5 | 38.5 | 34.3 | 33.8 | | 0.064 | 0 | 49.3 | 49.5 | 45 | 45 |
| | | 10 | 41.3 | 42 | 36.5 | 36 | | | 10 | 52 | 52.5 | 47 | 47 |
| | | 15 | 44.3 | 43.5 | 38.8 | 39 | | | 15 | 53.8 | 54 | 49.3 | 49 |
| | | 20 | 46.3 | 46.3 | 41 | 40 | | | 20 | 56.3 | 56.5 | 52 | 52.5 |
| 13–15 | 0.040 | 0 | 51.3 | 51 | 45 | 45.3 | 22–24 | 0.040 | 0 | 60 | 59.5 | 56 | 56 |
| | | 10 | 53.3 | 53.3 | 47.3 | 46.8 | | | 10 | 61.3 | 62 | 59 | 58.5 |
| | | 15 | 56 | 56 | 50.3 | 49.5 | | | 15 | 63.5 | 64 | 61 | 62 |
| | | 20 | 60.8 | 61 | 55 | 56 | | | 20 | 65.8 | 66 | 63 | 64 |
| | 0.047 | 0 | 50.5 | 51 | 45.5 | 45.5 | | 0.047 | 0 | 55 | 55 | 52.8 | 52.5 |
| | | 10 | 52.8 | 53 | 47 | 47 | | | 10 | 57.3 | 57.3 | 54.5 | 54.5 |
| | | 15 | 56 | 57 | 51.8 | 52.3 | | | 15 | 61.3 | 62 | 57 | 65.8 |
| | | 20 | 57 | 57 | 53.5 | 53.8 | | | 20 | 64.5 | 64 | 60.5 | 60.3 |
| | 0.054 | 0 | 48 | 48.5 | 42.5 | 43 | | 0.054 | 0 | 53.8 | 53.8 | 50.5 | 50.5 |
| | | 10 | 50.8 | 51 | 45.5 | 46 | | | 10 | 55.3 | 55 | 52 | 51.5 |
| | | 15 | 53 | 53.5 | 47 | 47 | | | 15 | 57.5 | 57.5 | 54 | 54 |
| | | 20 | 56.5 | 56.5 | 52 | 53 | | | 20 | 60.3 | 61.3 | 56.3 | 56.5 |
| | 0.064 | 0 | 44 | 43.5 | 40 | 40 | | 0.064 | 0 | 50 | 50.5 | 45.8 | 46 |
| | | 10 | 46.5 | 47 | 42 | 42.5 | | | 10 | 52 | 52.5 | 47 | 48 |
| | | 15 | 48.3 | 48.5 | 44.3 | 43.8 | | | 15 | 55 | 55.5 | 51 | 50.5 |
| | | 20 | 51.5 | 52.3 | 46.5 | 47 | | | 20 | 57.8 | 57.5 | 53.8 | 54 |

*Effect of soil parameters on he- buffalo leg sinkage in field condition:* Our results are presented in Table 1. The result showed that at 8–10% soil moisture content and cone index of 0.040 N/mm$^2$, the mean leg sinkage value on the front left leg and front right leg was 50.3 mm, and 50 mm respectively, when the load was not applied on the animal i.e. when the animal was walking without load. Similarly the leg sinkage was found 44.8 mm and 45 mm on rear left leg and rear right leg. The reason for more sinkage of both front legs could be due to body structure and weight distribution of he-buffalo on the legs. As the pull applied was increased from 0 to 10%, the leg sinkage increased on an average by 17% from its initial value under the front legs and 18.3% under the rear legs. The front legs sank more than rear legs of the test animal which may be due to the fact that he-buffaloes exerted force for pulling the load through their shoulder and hence sinkage on the front legs was more (Fig. 7). The data also revealed that the sinkage under the legs increased with increase in the application of load and follows the similar trend for all the values of load applied. The leg sinkage was more for less compacted surface when compared with more compacted soil with higher cone index value for the same level of soil moisture content which is due to the fact that hard surface offers greater resistance to penetration than soft soil surface. Similarly the leg sinkage was observed more for soil having higher moisture content than for the same soil with lower moisture content.

*Vertical reaction under the feet of he-buffalo*

The vertical reaction was determined by utilizing the mathematical model developed with the use of laboratory experiment data and the same is presented in Tables 2 and 3. It is clear from the data that vertical reaction under the hooves of the test animal increased with the increase in applied pull

Table 2. Actual value of body weight acts on vertical reaction when animal was pulling load at walk

| % pull of body weight | Vertical reaction force under front left leg and rear right leg | | | | Vertical reaction force under front right leg and rear left leg | | | |
|---|---|---|---|---|---|---|---|---|
| | front left legs (N) | rear right legs (N) | Total (N) | % increase from initial | front right legs (N) | rear left legs (N) | Total (N) | % increase from initial |
| 0 | 2933.19 | 2599.65 | 5532.84 | - | 2893.95 | 2599.65 | 5493.60 | - |
| 10 | 3041.10 | 2795.85 | 5836.68 | 5.31 | 3090.15 | 2844.9 | 5935.05 | 8.03 |
| 15 | 3237.30 | 3090.15 | 6329.45 | 14.35 | 3256.92 | 3001.86 | 6258.78 | 13.92 |
| 20 | 3335.40 | 3257.10 | 6592.5 | 19.18 | 3433.5 | 3090.15 | 6523.65 | 18.75 |

Table 3. Distribution of vertical reaction force on individual legs of he-buffalo at different load

| Sl. No. | % pull of body weight | % vertical reaction force at front legs | | % vertical reaction force at rear legs | |
|---|---|---|---|---|---|
| | | Left leg | Right leg | Left leg | Right leg |
| 1. | 0 | 53.01 | 52.21 | 47.06 | 47.06 |
| 2. | 10 | 52.10 | 52.94 | 48.20 | 47.94 |
| 3. | 15 | 51.16 | 51.14 | 47.50 | 48.91 |
| 4. | 20 | 51.14 | 52.63 | 47.00 | 48.43 |

for a particular soil moisture content and the soil surface hardness. The change in vertical reaction, on an average, was found 6.67, 14.14 and 19% from its initial value when the pull force increased from 0 to10, 15 and 20% respectively. The reaction on front legs was found always higher than the reactions at rear legs for all the values of pull applied. This may be due to the reason explained earlier. Fig. 8 represents the relationship between % pull of body weight applied and predicted vertical reaction force (N) under front and rear legs which indicates that as the pull increased the vertical reaction force at front and rear legs also increased. However, with the increase in pull, the vertical reaction force at rear legs increased sharply. By extrapolating the data it was learnt that the line of vertical reactions for both the legs crosses each other at pull value equivalent to 26.80 of the animal body weight. This may be due to weight transfer phenomenon and if the pull is applied beyond this limit then the he-buffalo under test may over turn if it does not adjust its centre of gravity (body) in line of pull.

Based on the result obtained from laboratory and field experiments, it is concluded that the animal leg sinkage increased or decreased significantly with the change in soil moisture content, soil hardness (cone index value) and magnitude of load applied. The results of field experiment also followed the similar trend. The body weight distribution of the test animal on front and rear legs were found as 57% and 43% respectively; due to this, the sinkage under fore legs was more than under the rear legs. The vertical reactive force was also found more under front legs than the rear legs but it was found equal at pull equivalent to 26.8% of body weight of he-buffalo. Extrapolation of the vertical reactive force data showed change of greater reactive force from front

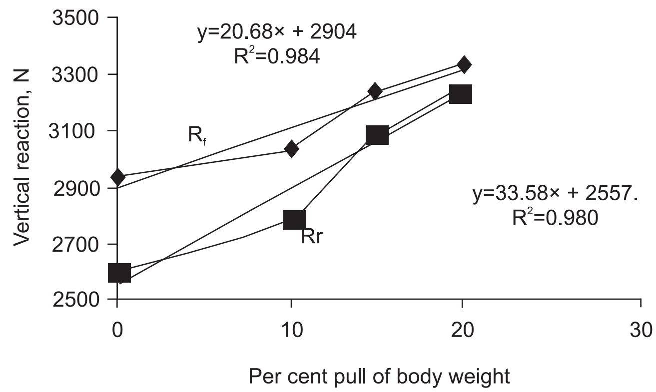



Fig. 8. Change of vertical reaction on front and rear legs with per cent pull.

legs to rear legs for a pull greater than 26.8% of body weight due to weight transfer phenomenon.

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