International Journal of Agricultural Technology 2022Vol. 18(5):2293-2306
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Effect of hitch height on traction and longitudinal stability during haulage operation using 2WD tractor

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Tapang, T., Chhetry, B. S. K. and Pranav, P. K. (2022). Effect of hitch height on traction and longitudinal stability during haulage operation using 2WD tractor. International Journal of Agricultural Technology 18(5):2293-2306.

Abstract It was observed that height of hitch of trailer plays important role on the haulage performance of tractor. A test tractor fitted with variable hitch height system was used to conduct haulage performance test and found that weight transfer from the front increased with the increased in hitch height thereby reducing wheel slip and enhancing tractive efficiency. Further, hitch height did not affect on draft, however, vertical force decreased with the increase of hitch height. Contrarily, lowered hitch height reduced the weight transfer from the front axle resulting in better longitudinal stability. Similar observations were made for paved and unpaved road conditions at various slopes. The longitudinal stability was estimated through measuring the front axle dynamic load by instrumenting the front axle. Therefore, it was concluded that the haulage performance of the tractor can be maximized by varying the hitch height to achieve better traction and stability.

Keywords: Front axle dynamic load, Haulage performance, Tractor stability, Traction, Variable hitch height

Introduction

There is an increasing trend to use tractors for haulage operations in India (Mandal and Maity, 2013). Though, tractors are primarily intended for tillage and various other field operations but popularly being used for transportation of agricultural produces, construction materials, and many others, including humans and animals. Further, Kumar (1994) estimated that 70% of tractor’s total using was for haulage related work. In India, transport/haulage operations are accounted for more than half of overall tractor use (Kumar *et al*., 2020). The basic design of the tractor is for field operations and little attention is paid to the requirements of the haulage work which resulted in poor performance and accidents. Tractor-related injuries caused by non-farming activities account to 54% (Kumar *et al*, 1998). Tractor-trailer combination is a potiential risk

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factor when heavy weight is loaded on trailer and traveling in steep slope (Arana *et al*., 2010). Fatalities were due to tractor/trailer overturn accounts for 37.8% of the total fatal accidents (Tiwari *et al*., 2004). In view of their greater use for transport operation, it is necessary to check their suitability from the consideration of haulage operation. Lack of optimization of the haulage performance parameters resulted in roll over of the tractor causing fatal accidents. The risk of tractor accidents during haulage depends on age of tractor, slope, type of payload etc. One of the possible approaches is to optimize some of the operational parameters of the tractor for haulage performance. The factors considered with a relevant in this context including payload, slope, drawbar hitch height, slip, type of surface and type of trailer. Many researchers (Abu-Hamdeh and Al-Jalil, 2004; Sahay and Tewari, 2004; Kumar and Pandey, 2009; Pranav *et al*., 2015; Kumar and Raheman, 2015; Rahmanian-Koushkaki *et al.* 2015, Kumar *et al*., 2017, Kumar *et al*., 2020) have theoretically analyzed the haulage parameters and concerned the advantages of variable hitch height for haulage operations in 2WD tractor. There was a variance between theoretical and practical analysis as many indeterminable factors that could not be taken into theoretical analysis. Therefore, this study was evaluated the haulage performance of the tractor by varying the hitch height at different payloads, slopes and surfaces.

Materials and methods

A 2WD tractor, mounted with a hydraulically controlled varying single hitch point, was selected for this study. A double-acting hydraulic cylinder was used to raise/lower the hitch height as shown in Figure 1. The hydraulic cylinder was powered by the existing hydraulic system and used an additional external direction control valve.

Figure 1. Hydraulically controlled variable single hitch point of test tractor

Development of instrumentations

The test tractor was instrumented to measure draft, vertical force, wheel slip and dynamic load on front axle which are elaborated as below.

Draft and vertical force

Two S-type load cell of 10 kN capacity each was measured the draft and vertical force of the trailer. One load cell was placed horizontally on a plate near hitch point for the measurement of draft, while for the measurement of vertical force, another load cell was placed vertically, just below the trailer hitch point between two plates as shown in Figure 2. The upper plate was made movable to accommodate turning negotiations while the lower plate was fixed. One end of the draft measuring load cell was connected to the trailer and the other end at the tractor hitch point. Prior to the attachment, the load cells were calibrated against known weights. The output data from the load cells during the experiment were recorded by a data logger (data tracker DT800).

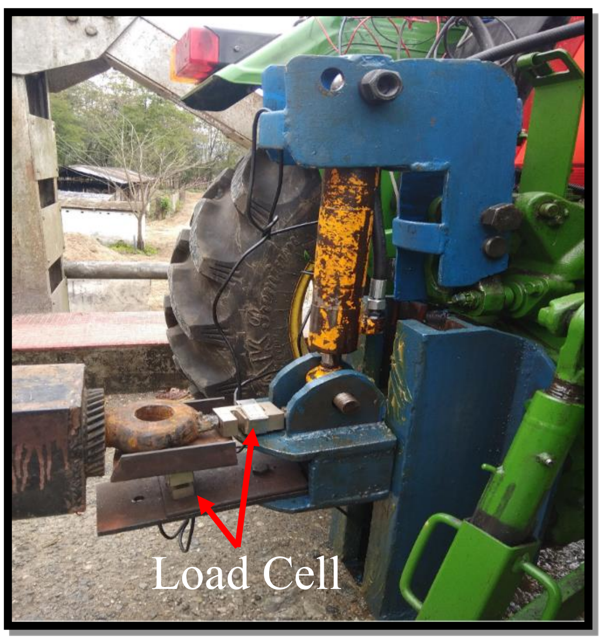


Figure 2. Load cells arrangement to measure draft and vertical force

Wheel slip

The calculation of wheel slip required the measurement of actual and theoretical speed were measured in the study.

Theoretical speed

To determine the theoretical speed of the tractor, a proximity switch was used and the number of revolutions of the rear wheel during the operation was recorded. A cast-iron rod having 6 mm diameter was bent and welded to form a circular ring having a diameter of 69 cm to fit the ring on the inner side of rear wheel rim as shown in Figure 3. Eighteen numbers of pegs were fitted on the inner side of the ring. The pegs were placed on the ring at a regular interval of 20 º. An arrangement was made to attach a proximity switch closer to the developed ring so that the voltage pulse generated when these pegs passed the proximity sensor can be detected by the data acquisition system. The proximity switch was placed at a sensing distance of 15 mm above the pegs. The power supply for the proximity switch was provided from the tractor's battery and the output from this sensor was captured through the counter channel of data tracker DT800 during the experiment.

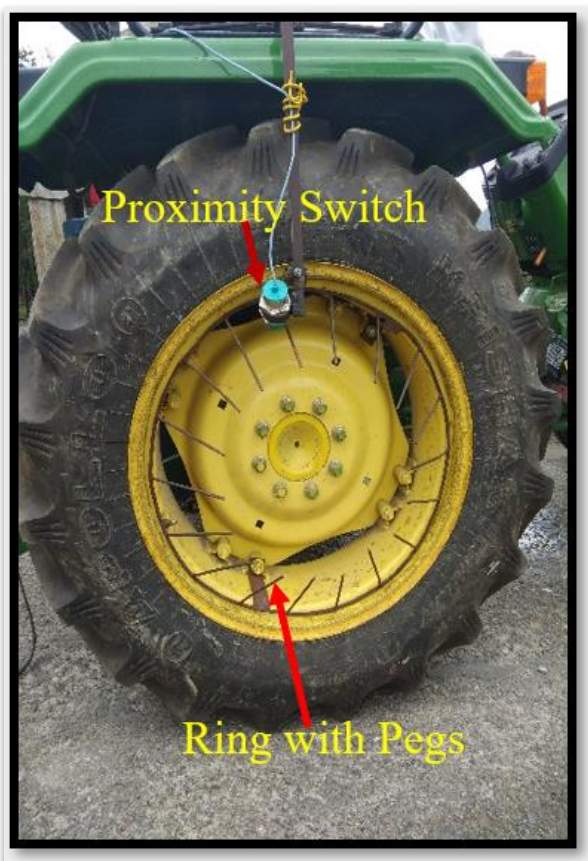


Figure 3. Set up for measuring theoretical speed

Actual speed

A non-contact type radar sensor was measured the actual speed of operation. A mild steel plate having dimensions of 600x120x6 mm was fixed at the rear, right and inner side of the tractor's mudguard as shown in Figure 4 in such a way that it made an angle of 35 ° with the horizontal. The sensor was facing forward in the direction of travel and the face of the sensor was placed at a height of 600 mm above the ground to unobstruct view of the ground. The input power for the sensor was obtained from the tractor's battery and the output of the radar sensor was stored in the data acquisition system (DT80). The radar sensor was connected to an analog channel of datalogger. Prior to the experiment, and the radar output was calibrated against known speed.

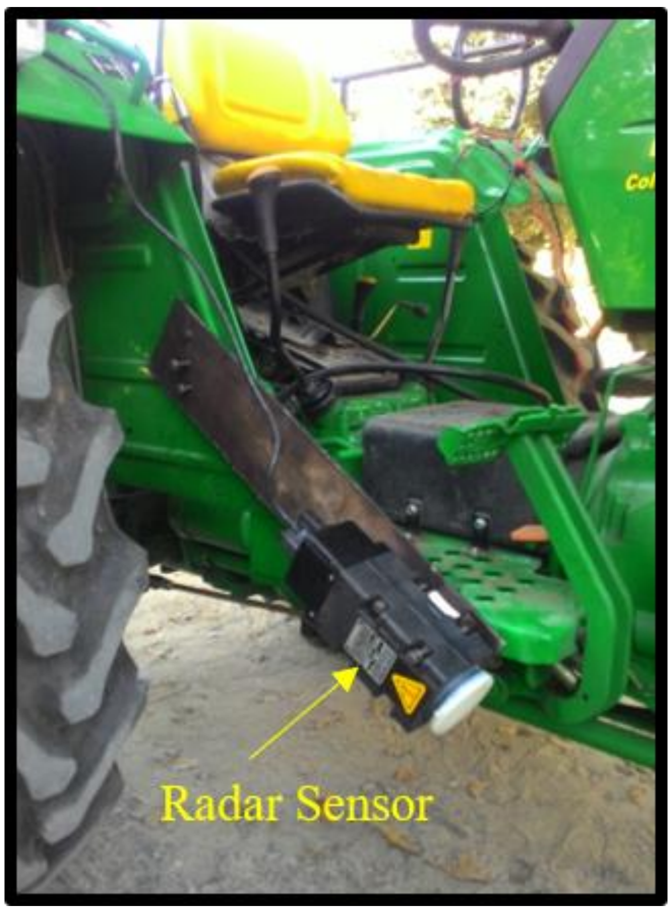


Figure 4. Set up for measuring actual speed of test tractor

Dynamic load in front axle

A S-type load cell having a capacity of 5 kN was installed on the front axle of the tractor to estimate the dynamic front axle load. The load cell was held just below, at the center of the front axle with the help of two rods and mounted horizontally to measure the vertical load acting on the front axle of the tractor. The far ends of rods were attached to kingpin of the tractor while the near ends were attached to the load cell.

Under static condition, the load on the front axle of the tractor was calibrated in the laboratory. The tractor was placed on platform balances from where the weight of the front and rear axles of the tractor can be obtained. The front axle of the tractor was jacked up until the reading on the front platform balance indicated 0 kg reading, i.e. the instant when the front axle of the tractor is just lifted off from the platform balance as shown in Figure 5.

The obtained readings during the experiment were recorded from the load cell and the corresponding values from the platform weighing balances to obtain a relationship between dynamic load in front axle with the load cell output.

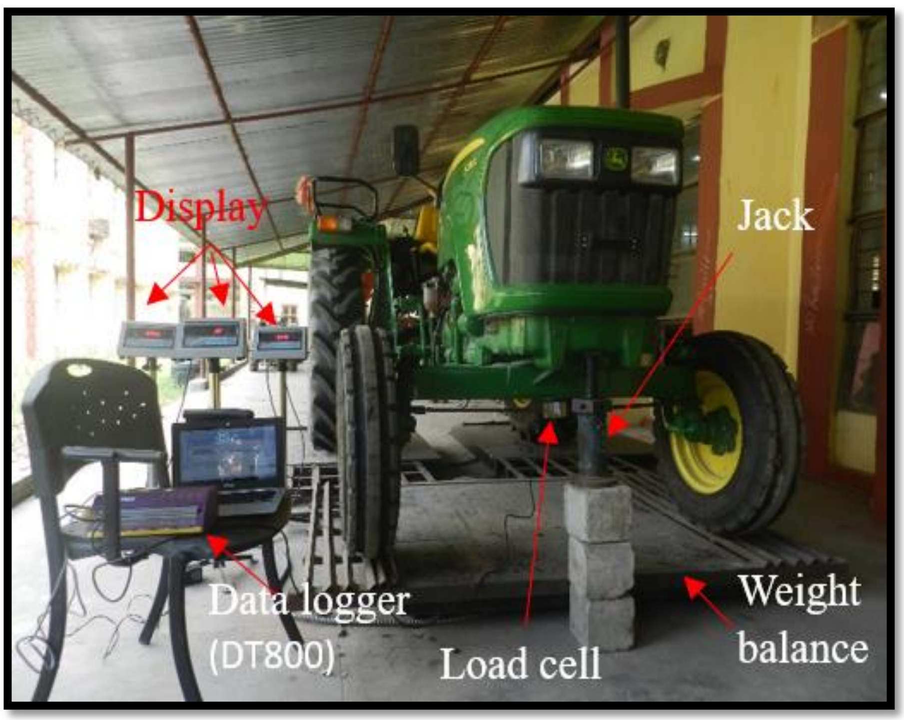


Figure 5. Load cell mounted tractor after being lifted by a jack for calibration

Calculation of tractive efficiency

A computer program was developed for calculating the tractive efficiency in Visual Basic 6.0 based on series of empirical equations. Input parameters on computer program were draft (kg), vertical force (kg), actual speed (m/s), theoretical speed (m/s), payload (kg), dynamic weight on front (kg), static weight on front (kg), rear static weight(kg), cone index (kpa), front and rear wheel size (width x rim diameter) (inch) and aspect ratio of front and rear tyres. The developed software contains a window where user can input various parameters. The draft and wheel slip were fed from the obtained values during the experiment. In the same window there is an "OK" button, which on clicking, calculates and displays the tractive efficiency on the same window as shown in Figure 6.

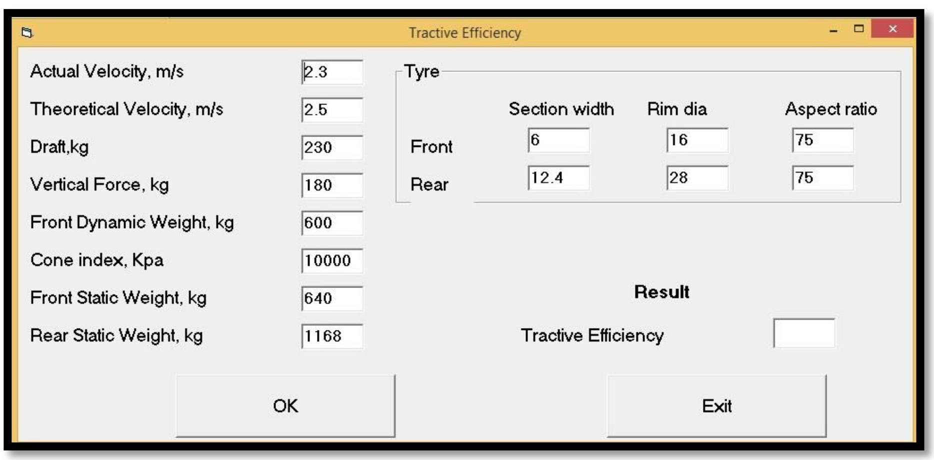


Figure 6. Window of the developed software

Experimental plan

The haulage performance test was conducted with three different payloads of 2000, 2500 and 3000 kg at three different hitch height 46.5, 56 and 61 cm above the ground surface. Tests were conducted on two different road conditions (unpaved and tarmacadam) at three different forward speeds (Low 3, High 1 and High 2 for unpaved surface, and High 1, High 2 and High 3 for the tarmacadam surface). Every combination of test was conducted for three road slope conditions (0°, 3.4° and 4.8° for tarmacadam surface and 0°, 2.86° and 5.61° for unpaved surfaces). Every combination of test was replicated thrice to compare the data statistically. Hence altogether 486 tests were conducted to draw solid conclusions.

Dependent parameters were draft (kg), vertical force (kg), dynamic load on front axle (kg), actual speed of operation (m/s) and theoretical speed of operation, m/s.

Experiment protocol

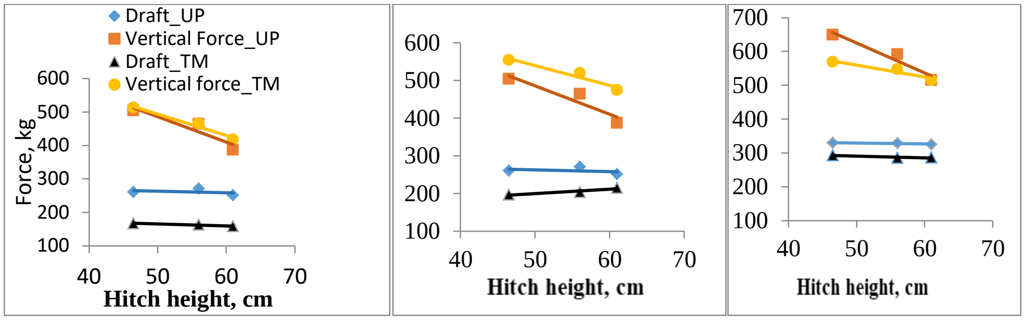
The test tractor with an unbalance trailer at different payloads was attached to the variable hitch bracket. The required hitch height was maintained by a manually operated direction control valve. Experiments were conducted for two road surfaces namely tarmacadam and unpaved. The engine speed was fixed at 1500 rpm throughout the experiment. To evalaute the effect of road surfaces on the tractor performance, three different road slopes for both surfaces were considered. The road slopes were measured using a dumpy level. Slope 1 represents 0 ° inclination for both the road types. Slope 2 denotes 3.4 ° and 2.86 ° for tarmacadam and unpaved road, respectively. Similarly, slope 3 indicates 4.8 ° and 5.61 ° for tarmacadam and unpaved road, respectively.

Results

The result presented under three heading namely effect of hitch height on draft and vertical force, slip and dynamic weight on front axle and tractive efficiency.

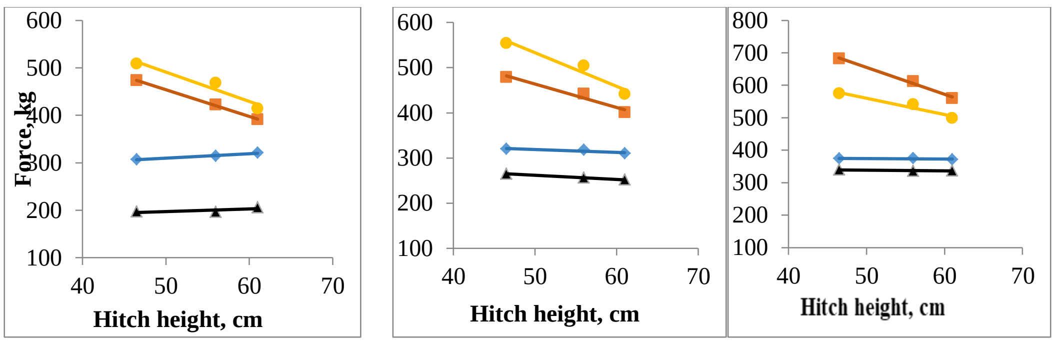
Effect of hitch height on draft and vertical force

The effect of hitch height on the draft and vertical force at different payloads and hitch heights on slope 1, 2 and 3 are shown in Figures 7- 9. It was observed that there was no notable deviation in draft with the variation in hitch height at all surfaces, payloads and slopes considered under the study. However, the vertical force varied with the change in hitch height. The hitch height had inversed relationship with the vertical force acting on the drawbar for both road surface on all the payloads and slopes. Under the different payloads and slopes considered in the study, the maximum difference in vertical force was found to be 134 kg (649 kg at 46.5 cm hitch height to 515 kg at hitch height of 61 cm) and the minimum difference in vertical force was found to be 78 kg (479 to 401 kg at hitch height of 46.5 cm and 61 cm, respectively) on unpaved surface while the maximum variation on tarmacadam surface was 113 kg, with a minimum variation of 54 kg.



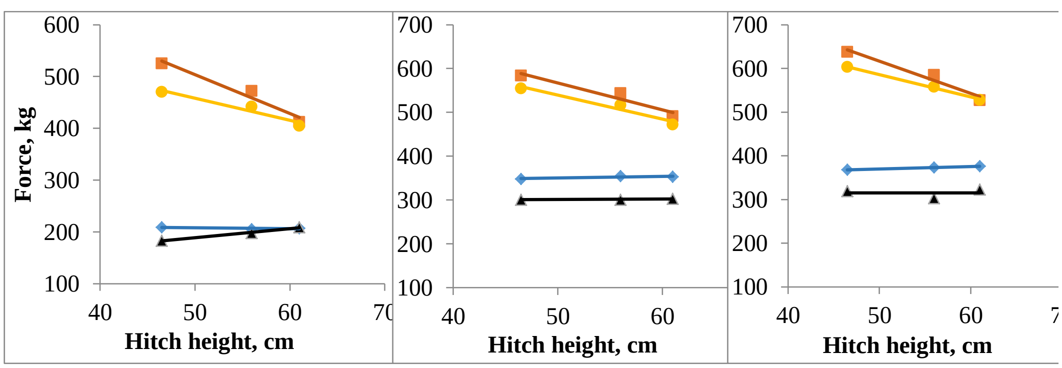
Payload=2000 kg Payload=2500 kg Payload=3000 kg

Figure 7. Effect of hitch height on the draft and vertical force at slope 1



Payload=2000 kg Payload=2500 kg Payload=3000 kg

Figure 8. Effect of hitch height on the draft and vertical force at slope 2

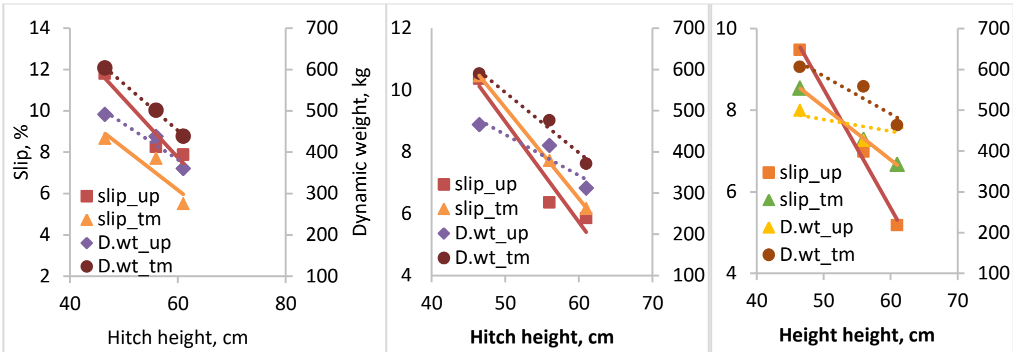


Payload=2000 kg Payload=2500 kg Payload=3000 kg

Figure 9. Effect of hitch height on the draft and vertical force at slope 3

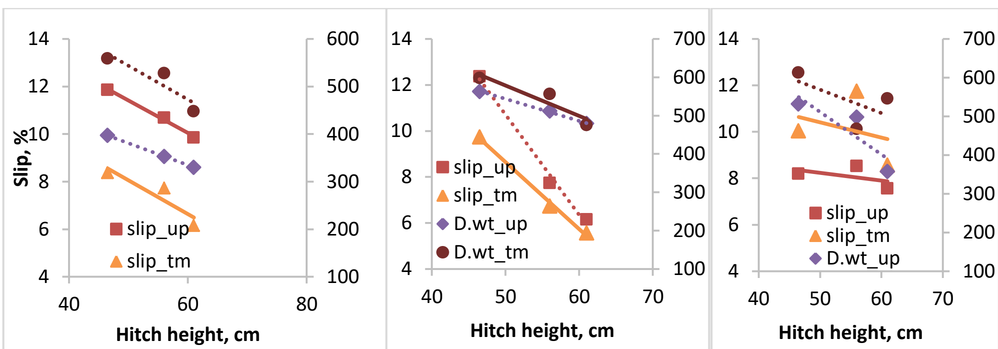
Effect of hitch height on slip and dynamic weight on front axle

The effect of hitch height on the slip and dynamic weight on front axle at different hitch heights at slope 1, 2 and 3 are shown in Figures 10-12. It was observed that the tractor wheel slip and dynamic load on front axle decreased on raising the hitch height. This phenomenon was observed for all the payload conditions at different slopes.



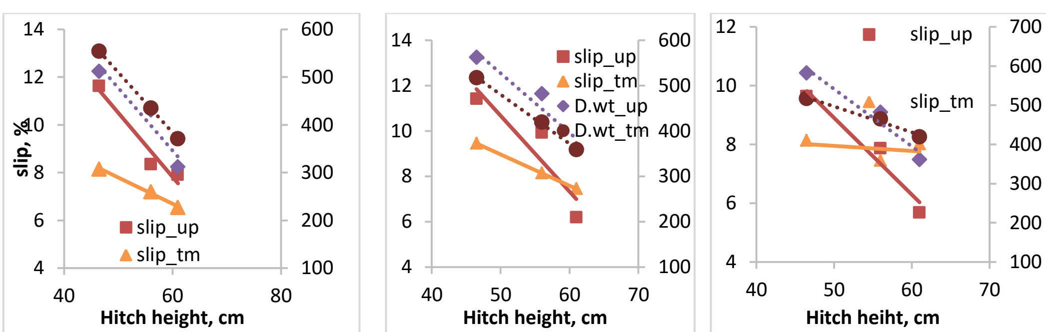
Payload = 2000 kg Payload = 2500 kg Payload = 3000 kg

Figure 10. Hitch height vs. slip and front axle dynamic load at slope 1



Payload = 2000 kg Payload = 2500 kg Payload = 3000 kg

Figure 11. Hitch height vs. slip and front axle dynamic load at slope **2**



Payload = 2000 kg Payload = 2500 kg Payload = 3000 kg

Figure 12. Hitch height Vs. slip and front axle dynamic load at slope 3

Effect of hitch height on tractive efficiency

The effect of hitch height on tractive efficiency was calculated using a computer program in visual basic software which are represented in Figure 13 for different payloads and hitch heights. In general, it was observed that tractive efficiency increased with the increased in hitch height from the ground.

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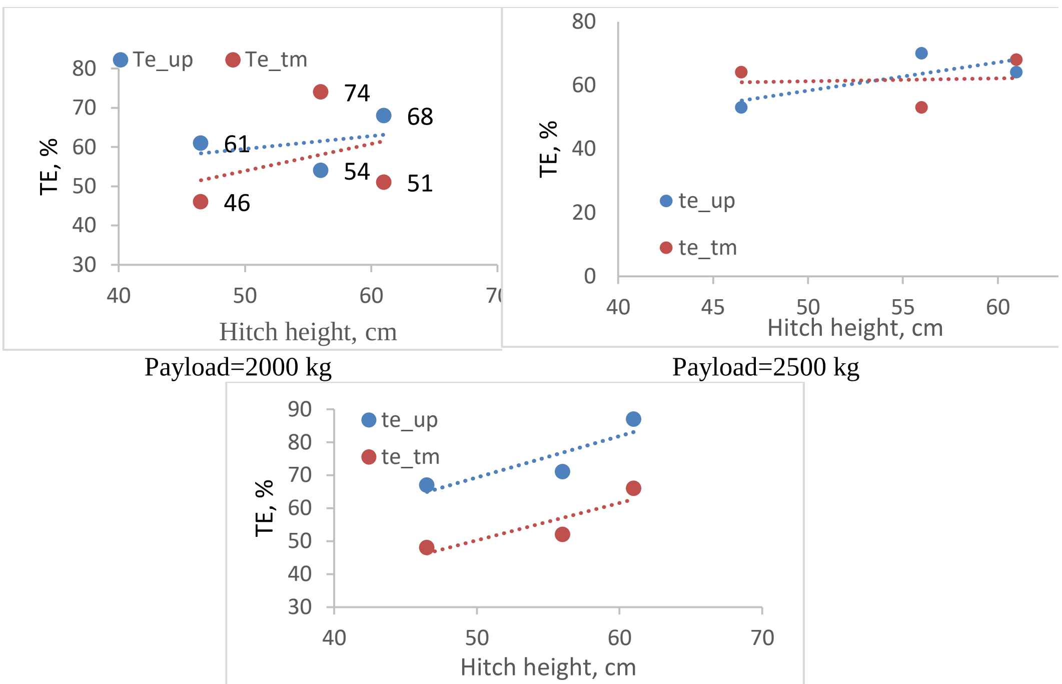

Payload=2000 kg

Payload=2500 kg

Payload=3000 kg

Figure 13. Effect of hitch height on tractive efficiency at different payloads

Discussion

For pulling a trailed implement by a two-wheel drive tractor, hitch height plays an important role in weight-transfer from the front to the rear axle. On the one hand, weight-transfer from the front enhances the tractive ability but on other hand, reduces the longitudinal stability. Stability and traction complement each other, and is very much desirable that an efficient tractor should have good amount of the both. The limitation of maximum pulling capacity of a tractor is either traction or stability, which vary with respect to road conditions and slopes. The concept of variable hitch heigth is a way to enhance the traction by compromising the stability and vise-versa.

To quantify the advantages of variable hitch height from the ground, this study was conducted and has found very useful results. The draft requirement of the trailer is not affected by the change in hitch height as the horizontal force requirement is not altered by the change in vertical location of pull. However, total force requirement will change. Accordingly, in this study, changes were observed in the vertical force and not in the horizontal force (draft) with respect to change in hitch height. The variation in the vertical force was observed due to the shifting of the centre of gravity of the unbalanced trailer towards the trailer-axle with the change in hitch height.

Weight-transfer plays an important role in stability and tractive ability of a 2WD tractor. The change in the weight-transfer has a direct effect on the wheel slip and tractive capacity of a tractor. Increased hitch height increased the weight-transfer from the front axle thus caused instability concern. Sahay and Tewari (2004) also indicated that increased hitch height limited the maximum pull capacity due to instability of the tractor at higher hitch points. Due to this increased weight-transfer at higher hitch heights, the wheel slip decreased. Kumar and Raheman (2015), Pranav *et al.* (2015) also reported that the wheel slip decreased with the increased hitch height. Higher rear axle load due to weight-transfer provided better traction which was achieved by increased hitch height. Pranav *et al.* (2015) also found that rear axle dynamic load increased with the increased hitch height. All together, it was observed that increased in hitch height enhanced the tractive efficiency. For safe operation of the tractor, the front axle load of the tractor must not be less than 20 % of the total weight of the tractor (Habarta, 1971). Since the tractor's stability is more important than traction, the height height can be raised for enhancing the traction only when adequate load is available on the front axle.

Therefore, it is conluded that a test tractor was successfully instrumented for measuring the draft, vertical force, dynamic load on the front axle, actual and theoretical speeds. With the increase in the hitch height, the wheel slip reduces which benefits the tractive performance of the tractor. The vertical force acting on the drawbar hitch point also decreases with the increased hitch height. The weight transfer from the front to the rear axle of the tractor decreases with the decrease in hitch height. This decrease in weight transfer warrants sufficient weight on the front axle to ensure a stable operation of the tractor under dynamic condition. Hence, the haulage performance of the tractor can be optimized by varying the hitch height during dynamic condition to achieve better traction and stability.

Acknowledgements

The authors would like to thank the Department of Science and Technology, Government of India for funding this project. The authors are thankfully acknowledge the support received from the tractor driver and support staff for conducting the experiments.

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(Received: 13 January 2022, accepted: 30 June 2022)