J. Trop. Agric. and Fd. Sc. 51(1)(2023): 1 – 5

Development of track-based system for tractor, paddy transplanter and high clearance prime mover in paddy field

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Abstract

Soft soil is a major problem that has become a critical issue faced by local farmers. An alternative solution is to use track-based wheels system to reduce the contact pressure on soil surface. A standard 71 kW (95 hp) tractor with a triangular steel track system, a 12.75kW (17 hp) high clearance prime mover were assembled with a triangular wood track system replacing each tyre respectively and a paddy transplanter was assembled with triangular steel track system replacing the rear wheels. For a tractor with 4-wheel drive, the trials include measuring soil compaction, soil shear strength and soil bulk density. As for high clearance prime mover and a paddy transplanter, the measured parameters were slip and machine sinkage. Based on the preliminary trial results, the maximum soil compaction was 1.3 MPa at 40 cm depth and the steel tracked tractor slightly increased soil compaction while causing no damage to the hardpan and did not damage the soil hardpan layer. The result for slippage and sinkage, high clearance prime mover obtained slippage of 3.3% using wooden shoes and sinkage of less than 30 cm, while the paddy transplanter obtained slippage of 11% using steel shoes and sinkage of less than 30 cm.

Keywords: steel track system, tractor high clearance, paddy transplanter, contact pressure, slippage sinkage

Introduction

Heavy and high contact pressure machines are the main contributor to soft soil problem in paddy field due to hardpan damage. Frequent use of heavy machines could damage the soil hardpan layer which would result in a soft soil condition (Mohd Zubir et al. 2013). Heavy machineries are also said to reduce the soil hardpan layer, which is required in paddy fields to prevent water leakage and support the weight of field machines while it is in operation (A. Hemmat and O. Taki, 2003). When this occurs, it will be hard to carry out any field operations, particularly soil tillage. Soft soil in rice fields has recently become a major issue for local farmers, preventing the use of heavy machinery for various field tasks.

Muda Agricultural Development Authority (MADA) has identified about 700 ha of its paddy fields that are facing this problem (Seminar Belanjawan MOA). Feedback received from MADA farmers suggested that the soft soil condition is caused by the extensive use of field machinery. Conventional tractors with standard tyre cannot function on soft soil conditions in paddy fields (Yuttana, K., Tofael, A. and Tomohiro, T. 2017). Flat geometry common tyre causes increased soil compaction (Mudarisov et al. 2020). Lightweight machinery is one of the initial steps to reduce hardpan damage. With the same soil contact area using narrow rubber wheels, the contact pressure can be reduced (T. Mandang et al. 2000) (G.Molari et al. 2011). However, the sinkage due to using narrow rubber wheels is a problem that affects the mobility of the machines in paddy fields. Current paddy prime movers such as tractors or transplanters use rubber wheels that produce high ground contact pressure onto the soil. With high ground contact pressure, the probability of machines sinking into the soil, or bogged down, is higher and can cause the machine to get stuck. This also can result in hardpan damage (Mandang, T. et al. 2000). There are some simple method to reduce topsoil compaction in agriculture sector by reducing tyre pressure to a minimal level, use of floating type of tyres, use of tracks or duals to replace singles, adopt radial-ply tyres instead of bias-ply tyres, install larger diameter tires to increase length of footprint, use tractors with four-wheel or front-wheel assist or tracks to spread the load over larger footprint area

Article history
Received: 2.8.2022
Accepted: 16.12.2022

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and using a proper ballast tractor for each field operation. However, not all of the methods mentioned are suitable for use in soft soil conditions, which are common in paddy plantations.

Malaysian Agricultural Research and Development Institute (MARDI) conducted a research to apply triangular track-based system to replace wheels for lightweight machinery involved in paddy mechanisation. This system would increase surface contact area of the machine in relation to the soil (ASAE S313.3 1999). This technology is targeted to improve mobility in soft soils and also for preventing it. The aim of this paper is to evaluate the effect of using a quad steel-tracked tractor on soil compaction, soil shear strength and soil bulk density and to obtain slippage and sinkage of a high clearance prime mover and a paddy transplanter. As a result, low-contact-pressure machinery is being produced, with the purpose of improving and increasing mobility in soft soils.

Materials and methods

Experiment plot

The preliminary trial was carried out from July 2013 until January 2014 at a selected plot in MARDI Seberang Perai. This research plot was filled with water about 3 – 4 cm deep. This plot was previously used for paddy production. The trial was done using three different paths inside the plot. The trial for tractor was done using three different paths inside the plot, with a straight stretch of 80 m long.

4WD Tractor

The tractor used was a 71 kW (95 hp) four wheel drive (4WD) tractor with front wheel assist (FWA). This tractor has a weight-to-power ratio of 32.77 kg/kW, before fitting it with triangular steel track system. The transmission was a power shuttle transmission with eight forward ranges and eight reverses. This tractor was chosen for its technical aspects and suitability to work in domestic paddy fields. A triangular steel track system was used to replace each of the tractor's wheels, as seen in (*Figure 1*). Each front track had an estimated mass of 500 kg and each rear track had an estimated mass of 750 kg. The track was formed in a triangular shape, with a driver sprocket at the top edge that drives a series of chain links. These chain links will move in a triangular shape around the driver sprocket, two idlers with one idler acting as the chain link adjustment tensioner and a series of rollers. Soil conditions were evaluated by the bulk density on a dry basis, the soil shear strength and the soil penetration. The parameters were taken before and after the passage of the tractor, at the beginning, halfway and at the end of the test area, with 3 replicates for each sampling area. The bulk density was evaluated using the cylinder method, where the cylinder was 50 mm in diameter and 55 mm tall. Samples were taken at the soil surface and at 15 cm deep. The soil shear strength was measured using a shear vane tester on the soil surface. A constant force of 10 N was applied to obtain the soil shear strength reading. The soil strength was measured up to 80 cm depth using a soil cone penetrometer with a base area of 323 mm^2 (ASABE 1999). The results from the soil compaction, soil shear strength and soil bulk densities were analysed using T-test (SPSS statistical analysis software). The increase in contact area induced by increase of vertical load and decrease of contact pressure (Taghavifar 2012).

High clearance prime mover

A 12.5 kW (17hp) four wheel drive (4WD) with four wheel steering (4WS) high clearance prime mover manufactured by ISEKI Japan was used (*Figure 2*). This prime mover has a weight-to-power ratio of 24.72 kg/kW. The front and rear rubber narrow wheels were replaced with triangular track system using wooden shoes special tractor is used for crop maintenance operations (fertiliser and herbicide spraying) in mechanised rice production. The high clearance prime mover was attached with a full load water tank. The triangular shaped track system used was equipped with wooden shoes for the high clearance prime mover. The mass is 200 kg approximately for each track. Both shoes measured 20 cm in width and 5 cm

Figure 1. Tractor equipped with four half tracks

Figure 2. High clearance prime mover with triangular track system using wooden shoes

in length of each track. The track consists of a driver sprocket at the top edge of the triangle, with two idlers located at the two other edges of it. A set of rollers are located between the two idlers.

Paddy transplanter

An 8.5 kW (11.5 hp) 4WD paddy transplanter manufactured by Kubota Japan was used (*Figure 3)* with weight-to-power ratio of 22.81 kg/kW. Only the narrow rear rubber wheels were replaced with triangular steel track system. This special prime mover is widely used for paddy transplanting using narrow-type wheels. The paddy transplanter was attached with a 150 kg load, to simulate the full capacity of seedlings trays that it could handle. The triangular shaped track system used was equipped with steel shoes for the paddy transplanter. Each track has an estimated mass of 200 kg. Both shoes also same as the high clearance prime move which are 5 cm long and 20 cm wide. The track made up of a driver sprocket at the top edge and two idlers at the other two sides of the triangle.

Figure 3. Paddy transplanter with triangular steel track system

Slippage

Slippage is a factor in computing tractive efficiency, amounting to a net loss of tractive power. It is defined as the amount of soil that deforms horizontally as a wheel passes over it. For obtaining slippage, two conditions were selected, tarmac and on the research plot. A distance of 50 m was selected, with the first 20 m travel was used to ensure the both machines obtain constant velocity. During the experiment, the high clearance prime mover used 2nd gear (high) and the paddy transplanter used low gear. Time taken for the machine to travel a distance of 30 m was measured and collected. This was repeated three times. The slippage was determined using the following formula;

$$\text{Slip} = \frac{Vtarmac - Vsoil}{Vtarmac} \times 100\%$$

Where:

Vtarmac = Average velocity on tarmac
Vsoil = Average velocity on soil

Results and discussion

Statistical analysis of the soil compaction, soil shear strength and soil bulk density do not show significant differences between before and after disturbances. The results of the 4WD tractor assembled with triangular steel-track system in terms of soil compaction is shown in (*Figure 4*). Before disturbance, the soil compaction was around 1 to 1.2 MPa at 20 cm to 60 cm. However, after disturbance by the quad tractor with steel tracks, the pattern changed. At 40 cm, the maximum soil compaction was 0.65 MPa at 10 cm depth, an increase of 0.1 MPa if compared to the maximum soil compaction before disturbance. This is where the tractor was able to obtain maximum traction for mobility in the field. The soil compaction decreased at 50 – 60 cm before following the same curve as before disturbance.

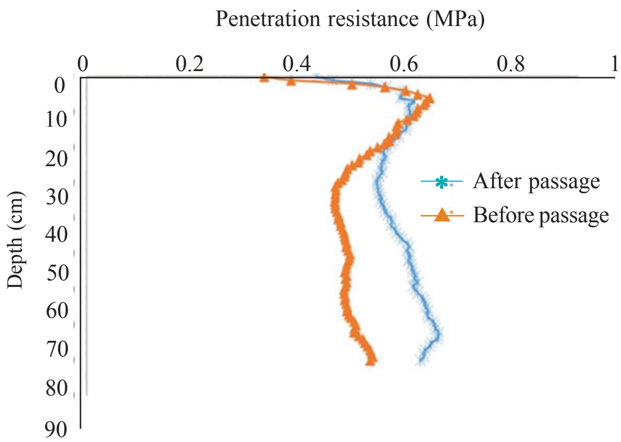

Figure. 4. Soil compaction before and after disturbance

This research also found that the quad tractor does not damage the hardpan layer in paddy fields, which is required for machine movement. The effects of soil shear strength using the quad tractor is shown in (*Figure 5*). The results before and after disturbance showed that the quad tractor did not produce a significant effect to the soil shear strength that could change the characteristics of the soil. This shows that the quad tractor does not shear the soil so much that could have adverse effects. (*Figure 6*) shows the effects of bulk density on dry basis before and after the passage of the quad tractor. The results showed that the bulk density decreased after the disturbance by the quad tractor. However, (D. Ansorge et al 2007) and (D J Campbell et al 1994) discussed that it was difficult in assessing soil compaction using dry bulk density alone.

For the high clearance prime mover, slippage of the track system using wooden shoes was 3.3%. The slippage for the paddy transplanter using steel tracks was 11%. The sinkage for the high clearance prime mover was 27 – 28 cm for the front tracks and 28 – 29 cm for the

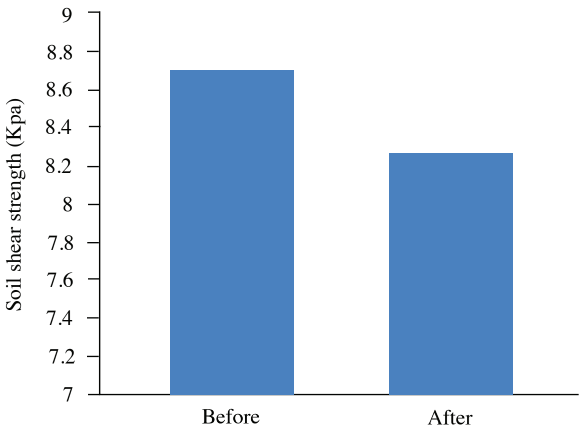

Figure 5. Soil shear strength (Kpa) before and after disturbance by four half-track tractors

Figure 7. High clearance prime mover sinkage at the research plot

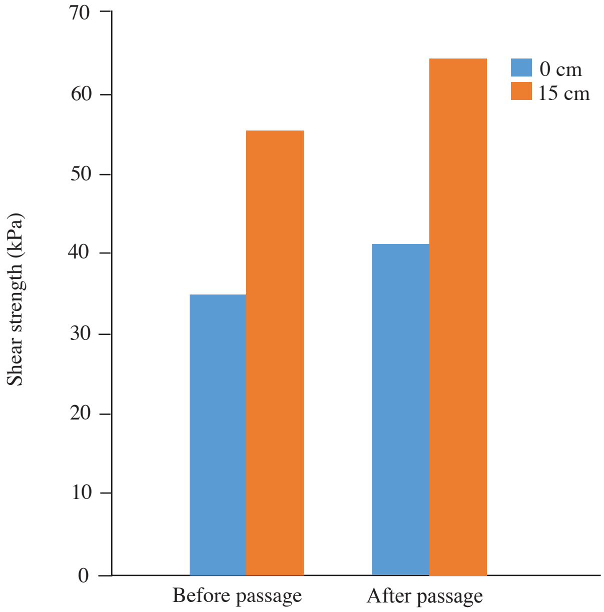

Figure 6. The effects of bulk density on dry basis before and after the passage of the quad tractor

Figure 8. Sinkage of paddy transplanter equipped with two half tracks

rear tracks *(Figure 7)*. For the paddy transplanter, the sinkage was 27 cm. *(Figure 8)* The high clearance prime mover used wooden shoes while the paddy transplanter used steel shoes. There was no significant difference using both shoes during sinkage. However, slip caused some differences between these two**.** Slip for the wooden shoes was smaller than that of the steel shoes. Although these data will need to be verified and evaluated in other locations of paddy fields, but it shows an indication of what the results would look like.

Conclusion

A quad steel-tracked tractor was evaluated to observe the effects on soil compaction, soil shear strength and soil bulk density. This preliminary trial showed that the maximum soil compaction was 1.3 MPa at 40 cm depth. The quad-track tractor did not damage the soil in terms of soil shearing and the quad-track tractor did not damage the soil hardpan layer. A high clearance prime mover and a paddy transplanter was evaluated to observe the slippage and the sinkage. This preliminary trial showed that: the high clearance prime mover obtained slippage of 3.3% using wooden and sinkage less than 30 cm. The paddy transplanter obtained slippage of 11% using steel shoes and sinkage of less than 30 cm. However, the wooden shoes lack traction due to its shape, a cylindrical block. It had difficulties in climbing and going down the bund. It also showed some heavy wear and tear when moving on tarmac. This material may not be good enough for the track system but can serve as a reference dimension and shape to select better material for the track shoes. These values will be further verified and evaluated in other locations.

Acknowledgement

The authors also acknowledge the technical support provided by the staff of the Engineering Research Centre (ER) Field mechanisation program MARDI HQ, ER Field mechanisation program MARDI Seberang Perai.

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