# Puddling Performance of Different Tilling Wheel Designs of the Float-Assisted Tiller in a Laboratory Soil Bin Set-up

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The float-assisted tiller is a popular farm implement used for lowland tillage in the Philippines. Lower cost per hectare is the main advantage of using the float-assisted tiller compared with traditional plowing and harrowing. Different designs of the float-assisted tiller have been developed and are commercially available. However, only a few studies have been published regarding float-assisted tiller design modifications and their corresponding performance evaluation.

The present study aimed to determine and compare the puddling performance of three designs (TW1, TW2 and TW3) of tilling wheel for the float-assisted tiller at different shaft speeds (200, 250 and 300 rpm). The experiments were done using a single tilling wheel in a laboratory soil bin filled with Maahas clay. Performance index was used as a measure of puddling performance.

Performance index was affected by the tilling wheel design, shaft speed, number of passes, and the combination of number of passes and shaft speed. The mean differences of performance index were not significant between TW1 and TW2. However, the mean differences of performance index between shaft speed and number of passes were all significant. Performance index was relatively higher with TW3 on the 1st pass for all shaft speeds.

The best tilling wheel design among the three is TW3 based on obtained performance index. Further study is recommended to verify results under actual field conditions.

Key Words: float-assisted tiller, performance index, tilling wheel design, tractive efficiency

## INTRODUCTION

Irrigated rice areas in the Philippines are generally cultivated under lowland conditions. Under these conditions, puddling is done as part of land preparation. Puddling is the process of churning the soil and water in a flooded field so as to form a homogenous mixture in such a way that the soil particles remain in suspension during the time of transplanting (Gupta and Visvanathan 1993). Puddling controls weeds, eases the transplanting operation, and reduces seepage and percolation. In conventional lowland tillage, plowing is done first to initially break and turn over the soil. Harrowing follows the plowing operation. During harrowing, large clods of soil are broken and puddled with water. Plowing is done again using either a moldboard plow or a rotavator (rotary tillers) under saturated soil conditions. The final part of tillage operation is then completed using peg tooth harrows to puddle the soil further and leave the surface levelled and ready for planting.

An alternative to conventional lowland tillage is the use of tillers. One of the popular tillers in the Philippines is the puddling-type floating or float-assisted tiller (Fig. 1). It consists of a front-mounted cage wheel (tilling wheel) and a flotation chamber on which the engine is mounted. The advantages of this tiller include suitability for water logged as well as normal field conditions; higher field capacity compared with the hand tractor; fewer passes required compared with traditional plowing and harrowing; lower cost per hectare; and ability to till edges and corners of the field (Calilung and Stickney 1985). However, some field studies of the float-assisted tiller indicate disadvantages such as poor maneuverability and difficulties in controlling its forward speed; displacement of plastic soil by the rounded bottom of the float which creates furrows and increases the cost and effort of subsequent operations; and difficulties in road transportation of the tiller (Manaligod and Stickney 1991).

The tilling wheel of the float-assisted tiller (Fig. 1) has the same configuration as that of the cage wheel
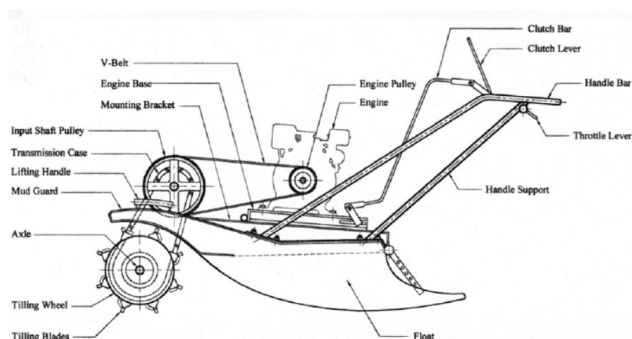
**Fig. 1.** Float-assisted tiller and its components (Source: AMTEC 2003).

of a typical lowland walking-type tractor in the Philippines. It has a smaller wheel diameter and lug angle than the cage wheel. It has spikes (tilling blades, Fig. 1) commonly of triangular shape. The tilling wheel functions as traction cum puddling device. The configuration of the tilling wheel produces traction and floatation for the tiller. The shaft speed of the tilling wheel is around 250 rpm (Manaligod and Stickney 1991) while it is only 40 rpm for the cage wheel of a walking-type tractor. The high shaft speed and spikes of the tilling wheel puddle the soil during operation.

The float-assisted tiller was first developed and introduced by Villaruz (1986). It has gained acceptance among small rice farmers especially in water-logged areas of the Philippines. Different designs of tiller for lowland application have been developed since its introduction. Design modifications include mainly the floatation chamber (shape, size) and tilling wheel parameters (blade shape, number and arrangement of blades, diameter, width, etc.) (AMTEC 2012; Baweg et al. 2008). Modifications were implemented on the basis of practical field experience to suit different field conditions. The design of the float-assisted tiller was improved or modified without adequate rigorous theoretical considerations. Data on the design modifications were kept only in the internal records of private and commercial fabricators of the float-assisted tiller. These data were not published and were assumed to be part of trade secrets.

Previous studies on the cage wheel design of the walking-type tractor for lowland operation showed only the characteristics of the cage wheel as traction device (Gee-Clough and Chancellor 1976; Salokhe and Gee-Clough 1988; Salokhe et al. 1989; Salokhe et al. 1994). On the other hand, studies on the effect of

type, shape, orientation and speed of operation of power tiller tynes under flooded soil conditions were done in order to optimize the tyne parameters (Beeny and Khoo 1970; Gupta and Visvanathan 1993; Salokhe et al. 1993; Shrivastava and Datta 2006). So far, only a few studies have been carried out on the different parameters of the tilling wheel of a float-assisted tiller (Fajardo et al. 2014, 2015; Fajardo and Suministrado 2015). Knowledge of the puddling characteristics and performance of the tilling wheel would contribute to the improvement of the design and optimize the use of the engine.

The objective of this study was to determine and compare the puddling performance of three designs of tilling wheels operated at different shaft speeds in a laboratory set-up.

## MATERIALS AND METHODS

### Soil Bin and Tilling Wheel
The study was conducted in a laboratory soil bin (200 cm long, 125 cm wide and 40 cm deep). The same soil bin and soil preparation technique previously used by Fajardo et al. (2014; 2015) and Fajardo and Suministrado (2015) were employed in this study. The soil used was Maahas clay with sand, silt and clay composition of 19.33%, 28.67%, and 52%, respectively. The particle density of the soil was 2.30 g/cm$^3$. The plastic limit, liquid limit and plasticity index were 42%, 71% and 29%, respectively. The soil bin (with soil) was filled up with water and a flooded condition was maintained for at least 24 h. The soil was saturated and the trial runs were conducted with 1 cm standing water.

Three designs of tilling wheels were used for this study and were designated as TW1, TW2 and TW3 (Fig. 2). The first tilling wheel (designated as TW1) has a diameter of 34.5 cm and a width of 47.5 cm. It has triangular blades or spikes in inverted V configuration. TW1 is widely used in Southern Luzon, Philippines, with some units distributed all over the Philippines. The second tilling wheel (TW2) has a diameter of 33 cm and a width of 47 cm. It has trapezoidal blades. TW2 is widely used in Northern Luzon, Philippines, with some units distributed all over the Philippines. The third tilling wheel (TW3) has a diameter of 34 cm and a width of 48 cm. It has trapezoidal blades. TW3 is widely used in Visayas and Mindanao, Philippines, with some units

**Fig. 2.** The three tilling wheel designs used in the study.



**Fig. 3.** Schematics of the experimental set-up (Source: Fajardo et al. 2014).

distributed all over the Philippines. The three tilling wheels have eight (8) lugs arranged equidistant to one another.

**Experimental Set-up**

The same experimental set-up used by Fajardo et al. (2014; 2015) and Fajardo and Suministrado (2015) was followed in this study. Figure 3 shows the schematics of the soil bin system and the measurement instrument set-up. Although the actual float-assisted tiller has a pair of tilling wheels, this study tested only one since both are of the same design. The tilling wheel was mounted on a carriage to provide a constant tilling depth of 10 cm (Fig. 3 and 4).

Each tilling wheel design was operated at different shaft speeds. For this study, the shaft speeds used were 200, 250, and 300 rpm while the forward speed used was 0.5 km $h^{-1}$. The shaft speed of the tilling wheel is around 250 rpm (Manaligod and Stickney 1991). For a given tilling wheel design and shaft speed, three trial runs were done. Three passes were done for each trial run. Although lowland field farmers use two passes of the tiller to prepare the soil, this experiment used three passes to find out if the number of passes had any effect on the puddling performance.

**Data Collection and Computations**

The same methodology for data collection, processing and computations used by Fajardo et al. (2014; 2015) and Fajardo and Suministrado (2015) was followed in this study. The output signals (in volts) from the signal amplifiers and speed signal processor were sent to a data acquisition unit (National Instruments USB6009). LabVIEW Signal Express 2010 software was used to record the signal data from the data acquisition unit and to convert those data in Microsoft Excel format.
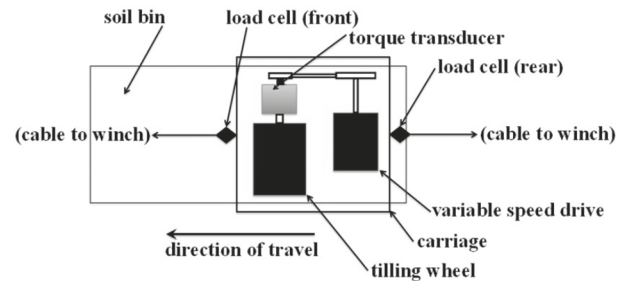
Two soil-water mixture samples for each pass were obtained using 100-mL aluminum cans and were then oven-dried for determination of puddling index as per Shrivastava and Datta (2006). The specific energy was calculated as per Shrivastava and Datta (2006). The performance index and tractive efficiency were computed as per Hendriadi and Salokhe (2002). Tractive efficiency and performance index were computed using the average axle power and average drawbar power.

Maximum draft, maximum axle power, puddling index and tractive efficiency were presented as puddling characteristics. The maximum draft and maximum axle power were the maximum value obtained in a single pass.

Performance index was presented as measure of puddling performance. Performance index is a measure of the energy used to disperse a volume of soil in a soil-water mixture. It was used to determine puddling performance and to select the best tilling wheel design. It shows how the power from the engine was utilized to puddle the soil.

ANOVA (at 95% level of significance) was used to determine the main effects of varying tilling wheel design, shaft speed and number of passes as well as their possible interaction effects on the draft, axle power, puddling index, tractive efficiency and performance index. Then, the mean comparisons using Tukey's HSD test were applied (at $p < 0.05$).

## RESULTS AND DISCUSSION

**Maximum Draft**

The maximum draft was significantly affected by the tilling wheel design (p = 0.0000), shaft speed (p = 0.0002), and number of passes (p = 0.0000). Maximum draft was also affected by the combinations of tilling
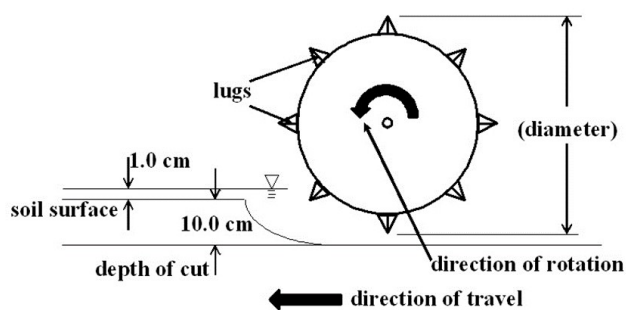
**Fig. 4.** Schematics of a tilling wheel set-up.

wheel design and number of passes (p = 0.0290); and number of passes and shaft speed (p = 0.0199). Moreover, at p < 0.05 by Tukey's HSD test, the mean differences of maximum draft among tilling wheel designs were all significant. The highest maximum draft of 187.7 N was with TW1 at 200 rpm on the 1st pass while the lowest was with TW3 (37.3 N) at 250 rpm on the 3rd pass (Fig. 5). It could be expected that TW2 and TW3 would produce higher draft due to the trapezoidal blades. Trapezoidal blades have larger surface area than the triangular blades of TW1. Larger surface area would have larger contact area that could produce higher draft. Maximum draft for all shaft speeds was relatively higher with TW1 (Fig. 5). The mean differences of maximum draft between 250 and 300 rpm were not significant. The mean differences of maximum draft between the 2nd and 3rd passes were not significant. Generally, the maximum draft decreased after the first pass for all tilling wheel designs and shaft speeds (Fig. 5).

**Maximum Axle Power**
The axle power describes the capacity of the wheel to move the tiller forward and at the same time puddle the soil. The draft and drawbar power are the manifestations of the axle power in moving the tiller forward. The maximum axle power could be used in determining prime mover size requirement.

The highest maximum axle power of 1,527.9 W was with TW1 at 300 rpm on the 1st pass while the lowest was with TW3 (458.3 W) at 200 rpm on the 3rd pass (Fig. 6). Maximum axle power for all shaft speeds was relatively higher with TW1 and was lower with TW3 for all shaft speeds and passes (Fig. 6). For this reason, TW1 would need a larger size of prime mover than TW3. As in the case of observations regarding maximum draft, it could also be expected that TW2 and TW3 would produce
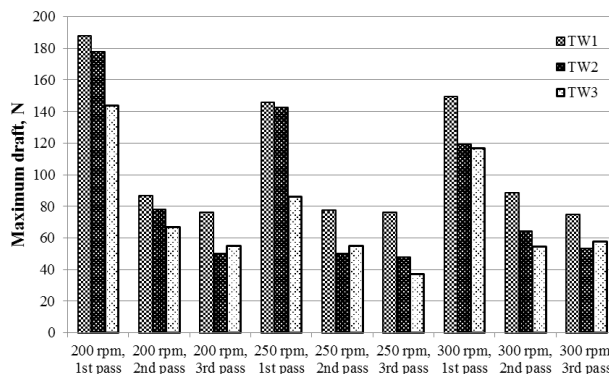


**Fig. 5.** Maximum draft of tilling wheels at different shaft speeds.
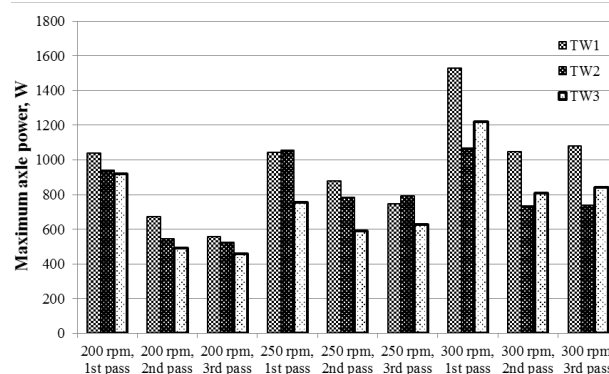


**Fig. 6.** Maximum axle power of tilling wheels at different shaft speeds.

higher axle power due to the trapezoidal blades. Larger contact area could also produce higher axle power. The result could have been affected by other tilling wheel parameters such as lug angle and its combinations with other parameters.

Maximum axle power is significantly affected by the tilling wheel design (p = 0.0000), shaft speed (p = 0.0000), and number of passes (p = 0.0000). Maximum axle power is also affected by the combinations of tilling wheel design and shaft speed (p = 0.0000); and number of passes and shaft speed (p = 0.0142). The mean differences of maximum axle power were not significant between TW2 and TW3. This could mean that use of TW2 and TW3 would not affect the engine size for the tiller. The mean differences of maximum axle power between shaft speeds were all significant. It could be observed that axle power was relatively higher at 300 rpm for all tilling wheels since shaft speed is directly related to power. On the other hand, the mean differences of maximum axle power between the 2nd and 3rd passes were not significant.

**Puddling Index**

The highest puddling index of 35.2% was at 200 rpm with TW1 (3rd pass) while the lowest (13.7%) was at 200 rpm with TW1 (1st pass) (Fig. 7). Generally, puddling index increased as the number of passes increased for all shaft speeds (Fig. 7).

Puddling index is significantly affected by the shaft speed (p = 0.0000), number of passes (p = 0.0050) and the combination of tilling wheel design and number of passes (p = 0.0258). The observation that puddling index was not affected by the tilling wheel design could be an indication that all three were effective in puddling the soil. On the other hand, higher puddling index was not observed at 300 rpm. It could be expected that higher tilling wheel rotation would puddle the soil more. This could be explained by the finding that mean differences of puddling index were significant only between 250 and 300 rpm. Mean differences of puddling index between passes were all significant.

**Tractive Efficiency**

Tractive efficiency is significantly affected by the tilling wheel design (p = 0.0001), shaft speed (p = 0.0000), number of passes (p = 0.0000), and the combination of number of passes and shaft speed (p = 0.0213). The mean differences of tractive efficiency between passes were all significant. Tractive efficiency was relatively higher with TW1 at the 2nd and 3rd passes (Fig. 8). TW1 was an effective traction device because it had the largest wheel diameter (34.5 cm) among the three. The mean differences of tractive efficiency were not significant between TW1 and TW2, and 250 and 300 rpm. The highest tractive efficiency of 2.5% was at 200 rpm (1st pass) with TW2 while the lowest was with TW3 (0.7 %) at 250 rpm on the 3rd pass (Fig. 8). Lower values of tractive efficiency were expected since the tilling wheel functions as a tractive cum tillage device. Tractive efficiency was relatively lower with TW3 for all shaft speeds and passes (Fig. 8). Moreover, increasing shaft speed did not affect traction performance.

**Performance Index**

The highest performance index was 483.4 $m^3 MJ^{-1}$ at 200 rpm (3rd pass) with TW1 while the lowest (81.6 $m^3 MJ^{-1}$) was also with TW1 at 300 rpm on the 1st pass (Fig. 9). Moreover, performance index was relatively higher with TW3 on the 1st pass at all shaft speeds (Fig. 9). Generally, the performance index increased
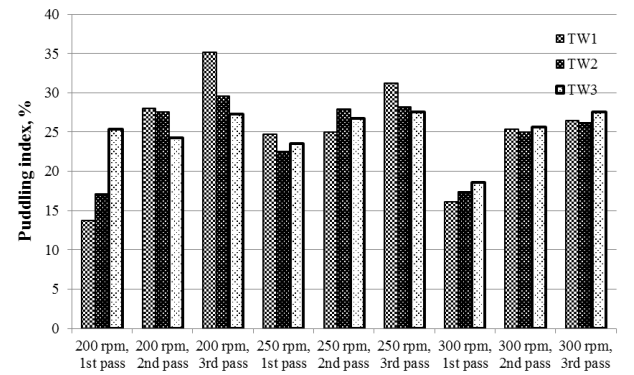


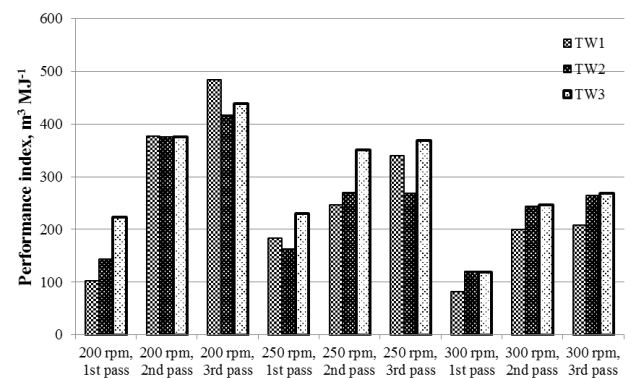**Fig. 7.** Puddling index of tilling wheels at different shaft speeds.



**Fig. 8.** Tractive efficiency of tilling wheels at different shaft speeds.
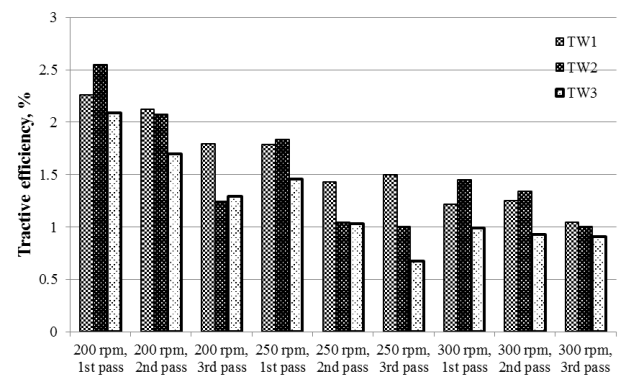


**Fig. 9.** Performance index of tilling wheels at different shaft speeds.

as the number of passes increased for all tilling wheels and shaft speeds (Fig. 9).

Performance index is significantly affected by the tilling wheel design (p = 0.0012), shaft speed (p = 0.0000), number of passes (p = 0.0000) and the combination of number of passes and shaft speed (p = 0.0001). The mean differences of performance index were not significant between TW1 and TW2. On the

other hand, the mean differences of performance index between shaft speed and number of passes were all significant. Performance index was higher with the 2nd and 3rd passes at 200 rpm for all tilling wheel designs (Fig. 9). This result could be expected since during the 1st pass, more energy is needed for soil cutting than soil puddling. It would take less energy to puddle the soil during the 2nd and 3rd passes. Less energy consumed would result in higher performance index. The performance index of TW3 was higher at 250 and 300 rpm for all passes (Fig. 9).

# CONCLUSION

Based on the results of this study, the following conclusions were made:

The best design of tilling wheel among the three was TW3. It had a higher performance index especially on the 1st and 2nd passes for all shaft speeds.

Although the tractive efficiency of TW3 was relatively lower, it should be operated at lower shaft speeds (200–250 rpm) since tractive efficiency was not significant between 250 and 300 rpm.

The results obtained should still be verified under actual field conditions. Performance evaluation under actual field conditions may consider the effects of a) floatation chamber design, b) land soaking condition, and c) presence of stubbles.

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