Effect of Lug Angle, Forward and Shaft Speeds, and Number of Passes on Puddling Characteristics and Performance of the Tilling Wheel of Float-Assisted Tiller

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ABSTRACT

Float-assisted tiller is one of the tillage equipment used for lowland rice production. A float-assisted tiller consists of a front-mounted cage wheel (tilling wheel) and a float on which the engine is mounted. The tilling wheel of the float-assisted tiller functions as a traction and puddling device. The paper studied the effect of lug angle (13° and 0°) on the puddling characteristics and performance of the tilling wheel at three forward speeds (0.5, 1.0 and 1.5 km h^{-1}), and three shaft speeds (200, 250 and 300 rev min^{-1}) and number of passes (1^{st}, 2^{nd} and 3^{rd}). The experiments were done using a single tilling wheel in a laboratory soil bin using Maahas clay.

The highest performance index of 1,334.6 m^3 MJ^{-1} was obtained on 3^{rd} pass using 13° lug angle set at 200 rev min^{-1} shaft speed and 1.5 km h^{-1} forward speed. Performance index was affected by the lug angle, forward speed and number of passes. The mean differences of performance index were significant only between 0.5 and 1.0 km h^{-1}. The highest tractive efficiency was 11.2% with 13° on the 1^{st} pass at 200 rev min^{-1} and 1.5 km h^{-1}. Tractive efficiency with 13° lug angle was relatively higher than with 0°. Tractive efficiency was significantly affected by the lug angle and forward speed. The mean differences of tractive efficiency were not significant between 1.0 and 1.5 km h^{-1}. The best lug angle for float-assisted tiller would be with 13° lug angle operating at 1.0 km h^{-1} because of high performance index and tractive efficiency.

Keywords: tilling wheel lug angle; float-assisted tiller; performance index

INTRODUCTION

Lowland tillage operation consists of three phases: 1) land soaking, in which water is absorbed until the soil is saturated; 2) plowing, which is the initial breaking and turning over of the soil; and 3) harrowing, during which big clods of soil are broken and puddled with water (De Datta, 1981).

Plowing is done using any of the following: carabao (*Bubalus Bubalis*) (with moldboard or disc plow); two-wheel (walking-type) tractor (with moldboard or disc plow or rotavator/rotary tiller); or float-assisted tiller. Harrowing is done using any of the following: carabao (with comb-tooth harrow); two-wheel tractor (with comb-tooth harrow or rotavator); or float-assisted tiller. Cage wheels on the tractor are needed for traction in all soil types and these also help puddle the soil (De Datta, 1981).

The traditional tillage method for lowland rice is puddling. Puddling helps retain standing water in the rice field by producing fine soil particles but reducing soil porosity, thus reducing seepage. Puddling is also beneficial because it levels the soil surface and provides a homogenized soil with no clods. Puddling has been widely adopted because it provides ease of transplanting (De Datta, 1981).

One of the equipment used for puddling is the float-assisted tiller. It consists of a front-mounted cage wheel plus a flotation chamber on which the engine is mounted (Fajardo *et al.*, 2014). The cage wheel of the tiller is called tilling wheel. The tilling wheel of the float-assist tiller has the same configuration as the cage wheel of two-wheel tractor but has smaller wheel diameter and lug angle. The tilling wheel has spikes commonly of triangular shape. The cage wheel-like configuration of the tilling wheel produces traction and flotation for the tiller while the relatively high wheel rotation and spikes resemble the puddling effect of the blades of rotary tillers. The advantages of float-assisted tiller over the use of walking-type tractor with implement include: 1) higher field capacity; 2) fewer passes are required which results to lower cost per hectare; and 3) ability to till edges and corners of the field (Calilung and Stickney, 1985).

The different designs of float-assisted tillers in the Philippines have evolved from the design of Villaruz (1986). Design modifications of the tiller include float design, blade configurations, and other tilling wheel configurations. Modifications were implemented on the basis of practical field experience to suit different field conditions (i.e. different soil texture, land soaking condition, presence or absence of stubbles, etc.) (Fajardo *et al.*, 2014). However, data on the design modification of tilling wheel and tiller were confined only in the internal records of private and commercial fabricators of float-assisted tiller. These data were not published and was assumed to be part of trade secrets.

Published studies regarding the design improvement and performance of tilling wheel for float-assisted tiller are limited. The different studies conducted on the cage wheel design for lowland operation, e.g. Gee-clough and Chancellor (1976); Salokhe and Gee-clough (1988); Salokhe *et al.* (1989); and Salokhe *et al.* (1994), showed the characteristic of cage wheel as traction device. On the other hand, studies conducted on the performance of blades of rotary tiller for lowland operation, e.g. Beeny and Khoo (1970); Gupta and Visvanathan (1993); Salokhe *et al.* (1993); and Shrivastava and Datta (2006), showed the characteristic of rotary tiller blades as tillage (puddling) device. Previous studies conducted, e.g. Gee-Clough *et al.* (1990); Manaligod and Stickney (1991); and Baweg *et al.* (2008), regarding the float-assisted tillers were on the field performance of the tiller but not on the puddling characteristics and performance of the tilling wheel.

Fajardo *et al.* (2014) determined the puddling characteristics of the tilling wheel using two lug angles at different shaft speeds. Results showed that the tilling wheel with 13° lug angle has higher performance index and tractive efficiency. However, the said study was conducted only at 0.5 km h^{-1} forward speed. Forward speed of float-assisted tiller in an actual operation may vary depending on the field condition and operation. Forward speed may be affected by soil type, soil soaking condition, presence of stubbles and weeds, operator control, and design of float. The study by Gee-Clough *et al.* (1990) observed that the float-assisted tiller moved so fast on the 3rd pass that operators rapidly became tired. With varying forward speed, puddling characteristics and performance also vary.

This study presented the effect of lug angle on the puddling characteristics and performance of the tilling wheel of float-assisted tiller at different forward and shaft speeds, and number of passes in a laboratory setting.

MATERIALS AND METHODS

Soil Bin

The study was conducted in the laboratory soil bin previously described by Fajardo *et al.* (2014). The soil bin was filled with Maahas clay soil obtained from the lowland rice farm of Agripark, College of

Agriculture and Food Science (CAFS), UPLB, Laguna, Philippines. The soil has textural class of clay with sand, silt and clay composition of 19.3%, 28.7%, and 52%, respectively. The particle density of the soil was 2.3 g cm^{-3}. The plastic limit was determined to be 42% while the liquid limit was found to be 71%. Plasticity index was 29%. Procedures in the determination of plastic and liquid limit, and plasticity index were based from Bowles (1992). The soil was air-dried or sun-dried and then pulverized using a hammer mill with six (6) mm screen opening. Each soil layer (3-4 cm) placed in the soil bin was compacted (twice) using a concrete compacting block with weight of about 45 kg. A total of 5 soil sample layers were used in every experimental run.

Tilling Wheel

The same tilling wheel used by Fajardo *et al.* (2014) was used for this study. The tilling wheel has a diameter of 34.5 cm and width of 47.5 cm. The tilling wheel has eight lugs arranged equidistant to each other. The tilling wheel normal lug angle was about 13° with triangular as default blade shape. The lug angles used were 0° and 13°, both with triangular blades. The zero degree lug angle was used by most of commercially-available float-assisted tiller (AMTEC, 2012). Lug angle measurement is described in Fajardo *et al.* (2014). The tilling wheel was operated at three shaft speeds (200, 250 and 300 rev min^{-1}) and three forward speeds (0.5, 1.0 and 1.5 km h^{-1}). The shaft speeds and forward speeds used were based on the results of previous study by Manaligod and Stickney (1991); and test data results of AMTEC (2012) on different float-assisted tillers. Three passes were done for each experimental run. Although two passes are done on actual lowland field, three passes were made to determine whether the number of passes, other than the lug angle, forward and shaft speeds, would affect the puddling performance.

Experimental Set up

The same experimental setup described in Fajardo *et al.* (2014) was used in this study. The tilling wheel (one piece) was mounted on a carriage above the soil bin. The carriage moved (back and forth) in a fixed direction along the rails. The carriage was pulled by a variable speed motor through cable and winch assembly. The forward speed of the carriage was set before the experimental runs on an empty soil bin with the tilling wheel mounted on the carriage. Torque transducer and speed sensor were installed to determine the torque and shaft speed, respectively. Tension load cell (front) was installed to determine the pulling force while another load cell (rear) was installed to measure forward thrust. The load cells (front and rear) and the torque transducer were connected to individual signal amplifier. The shaft speed sensor was connected to a signal processor. Weights on both sides of the carriage were also placed in order to eliminate the effect of lift.

The soil bin contains the same soil sample, in quantity and amount of water (saturated condition). As such, any changes in bulk density, moisture content, and depth were assumed as unlikely to occur. Before the start of each run, the soil-bin was filled up with water and this flooded condition was maintained for at least 24 hours to saturate the soil. The height of water standing on the soil surface before each trial run was approximately 1 cm. The depth of cut was maintained at 10 cm. For each tilling wheel variable (lug angle, shaft and forward speed), three trial runs consisting of three passes each were conducted. Data were averaged for a given lug angle, shaft speed, forward speed, and number of passes.

Data Collection and Processing

The output signals (in volts, V) from the signal amplifiers and speed signal processor were sent to a data acquisition unit (National Instruments (NI) USB6009). The software LabVIEW Signal Express 2010 was used to record the signals from the NI USB6009 and convert those data into Microsoft Excel accessible format. The time of run was recorded using a hand-held stopwatch. Soil-water mixture samples (two) for each pass were obtained using 100 ml aluminum cans and were then oven-dried for determination of puddling index. Puddling index was computed using the following equation:

$$PI = (Vss/Vsw) \times 100 \qquad \textit{Equation 1}$$

where: PI = puddling index (%);

Vss = volume of settled soil (ml) (equal to Vsw less volume of water) and;
Vsw = volume of soil plus water (ml) (equal to volume of aluminum cans, 100 ml).

Data were imported to Microsoft Excel and underwent smoothing process to remove noise. The equation used was the moving average algorithm given by the equation:

$$(y_k)_s = \sum_{i=-n}^{i=n} \frac{y_{k+1}}{(2n+1)} \qquad \textit{Equation 2}$$

where: $(y_k)_s$ = the smoothed point;
y_{k+1} = sum of points of the raw data;
n = number of points of the raw data (2000).

After the smoothing process, data were then converted to its appropriate units using Microsoft Excel. Load cells readings (V) were converted to Newton (N) while torque transducer readings (V) were converted to Newton-meter (Nm). Shaft speed readings were converted to revolutions-per-minute (rev min^{-1}) by multiplying the values by 1000.

The no load forces (front and rear) were determined by pulling the carriage (while the tilling wheel was mounted) in the empty soil bin. Front load force obtained in an actual run was adjusted by subtracting the no-load (front) values from the values obtained from all runs. The adjusted value is referred to as net front load force. The computational adjustment eliminated the effect of force from the weight of carriage and cable. Rear load force obtained in an actual run was adjusted by subtracting the no-load (rear) values from the values obtained from all runs. The adjusted value is referred to as net rear load force. The adjustments made eliminated the effect of the weight of the cable connected to the rear load cell. This was done in order to isolate the draft produced by the tilling wheel. The net draft was determined by subtracting the net front load cell force from the net rear load cell force.

The specific energy and performance index were calculated using the following formulas (Shrivastava and Datta, 2006):

$$Es = (Dp + Pa) / Vs \qquad \textit{Equation 3}$$

$$Dp = Fh \times Vt \qquad \textit{Equation 4}$$

$$Pa = (2 \times \pi \times Q \times w)/60 \qquad \textit{Equation 5}$$

$$PEI = PI/Es \qquad \textit{Equation 6}$$

where: Es = specific energy requirements (J m^{-3});
Dp = drawbar power;
Fh = draft force (N);
Vt = forward speed of implement (m s^{-1});
Pa = axle power;
Q = torque (Nm) and;
w = shaft speed (rev min^{-1});
Vs = volume of soil puddled per unit time (m^3 s^{-1});
PEI = performance index; and PI = puddling index (%).

The tractive efficiency was computed using the equation (Hendriadi and Salokhe, 2002):

$$n = (Dp/Pa) \times 100 \qquad \textit{Equation 7}$$

where: n = tractive efficiency (%);
Dp = drawbar power (W) and;
Pa = axle power (W).

Analysis of variance (ANOVA at 95% level of significance, full factorial) was used to determine the effects of independent variables (lug angle, forward speed, shaft speed, and number of passes) as well as their possible interaction effects on the dependent variables. The dependent variables include the puddling characteristics (maximum draft, average drawbar power, maximum axle power, average axle power and puddling index) and performance (performance index and tractive efficiency) of the tilling wheel. The mean comparisons using the Tukey's Honest Significant Difference (Tukey's HSD) test were applied (at $p<0.05$).

RESULTS AND DISCUSSION

Puddling Characteristics of Tilling Wheel at Two Lug Angles

Maximum Draft at Two Lug Angles

The maximum draft is the maximum value obtained in a single pass. Maximum draft was relatively higher with 13° lug angle for all forward and shaft speeds (Figures 1 and 2). The highest maximum draft of 191 N was obtained with 13° lug angle at 200 rev min^{-1} shaft speed and 1.5 km h^{-1} forward speed (Figure 1) on the 1st pass. The highest maximum draft of 166.3 N with 0° lug angle was obtained at 200 rev min^{-1} and 1.5 km h^{-1} (Figure 2) on the 1st pass.

On the average, maximum draft with 13° was higher by about 40% (percentage difference) than with 0° on the 1st pass while by about 68% on the 2nd pass. In general, maximum draft was obtained on the 1st pass for all lug angles, forward and shaft speeds. It was also noted that there was a sharp decrease in maximum draft after the 1st pass, for 13° and 0° lug angle, at 1.0 km h^{-1}, which could be expected. On the 1st pass, the lugs and blade were acting on a solid soil in which lower slip could be achieved. On the 2nd pass, the lugs and blade were acting on a loose soil, resulting to lower draft. The 1st pass achieved the initial cutting and puddling of soil while the 2nd pass promoted further puddling.

Statistical analysis showed that maximum draft is significantly affected by the forward speed ($p=0.0000$), shaft speed ($p=0.0030$) and number of passes ($p=0.0000$). Draft is significantly affected by the combinations of: 1) lug angle and forward speed ($p=0.0000$); 2) lug angle and shaft speed ($p=0.0286$); forward speed and number of passes ($p=0.0000$); and 4) forward and shaft speeds ($p=0.0000$).

Moreover, at $p<0.05$ by Tukey's HSD test, the mean differences of maximum draft among forward speeds and number of passes were all significant. On the other hand, the mean differences of maximum draft among shaft speeds were significant only between 250 and 300 rev min^{-1}.

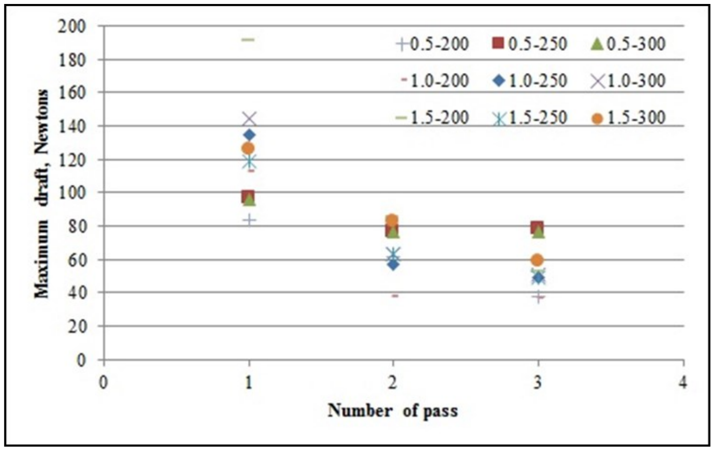

Figure 1. Maximum draft with 13° lug angle at varying forward (0.5, 1.0 and 1.5 km h^{-1}) and shaft speeds (200, 250 and 300 rev min^{-1}).

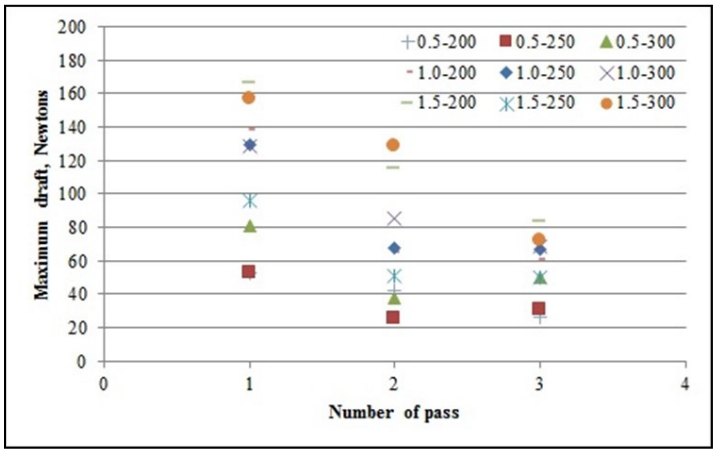

Figure 2. Maximum draft with 0° lug angle at varying forward (0.5, 1.0 and 1.5 km h^{-1}) and shaft speeds (200, 250 and 300 rev min^{-1}).

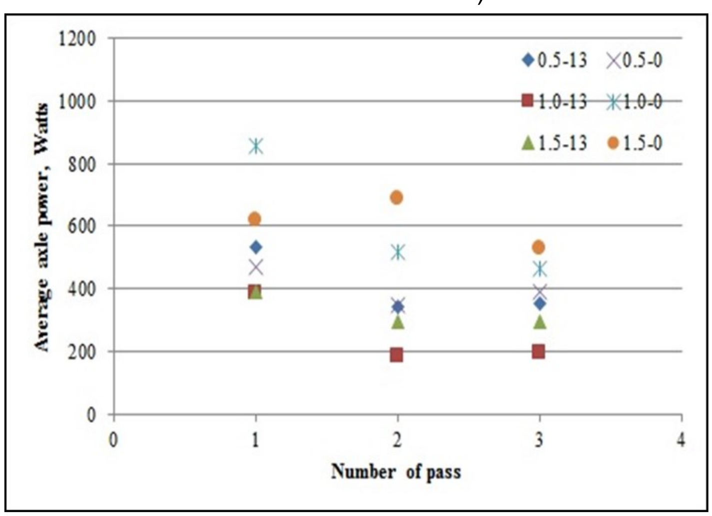

Figure 3. Average axle power with different lug angle (0° and 13°), forward speed (0.5, 1.0 and 1.5 km h^{-1}) and 200 rev min^{-1} shaft speed.

Average Axle Power at Two Lug Angles

A lower value of axle power is desired for a rotating element such as a tilling wheel. In general, average axle power increased as shaft speed increased for all forward speed and number of passes (Figures 3, 4 and 5). This is expected since axle power is directly related to shaft speed. Also, average axle power was generally higher with 0° lug angle for all forward speeds, shaft speeds and number of passes. The 0° lug angle is the lug angle used by most of commercially-available float-assisted tillers in the Philippines. The lowest average axle power of 182.2 W was obtained on the 1st pass with 13° at 250 rev min^{-1} and 1.0 km h^{-1} (Figure 4). The lowest average axle power with 0° was 346.3 W obtained on the 2nd pass at 200 rev min^{-1} and 0.5 km h^{-1} (Figure 3).

Average axle power was higher at 0.5 km h^{-1} than at 1.5 km h^{-1} with 13° lug angle on the 1st pass. The average percent difference was 25%. On the other hand, average axle power was higher at 1.5 km h^{-1} than at 0.5 km h^{-1} with 0° on the 1st pass. The average percent difference was also 25%. Theoretically, higher axle power should be observed with higher forward speed. Higher forward speed would need additional power to propel the machine. The lug angle could have an effect on the differences. With 0° lug angle, axle power was utilized more for puddling than traction. On the other hand, axle power was utilized more for traction than puddling with 13° lug angle.

Average axle power was significantly affected by the lug angle (p=0.0000), forward speed (p=0.0000), number of passes (p=0.0000) and shaft speed (p=0.0000). Similar results were obtained by Fajardo *et al.* (2014). The combinations of: 1) lug angle and forward speed (p=0.0000); 2) forward speed and number of passes (p=0.0003); 3) lug angle and shaft speed (p=0.0000); 4) forward and shaft speeds (p=0.0002); and 5) lug angle, forward speed and number of passes (p=0.0303) also have significant effects on the average axle power. The mean differences of average axle power among forward speeds were not significant between 0.5 and 1.0 km h^{-1}. The mean differences of average axle power among passes were not significant between 2nd and 3rd pass. The mean differences of average

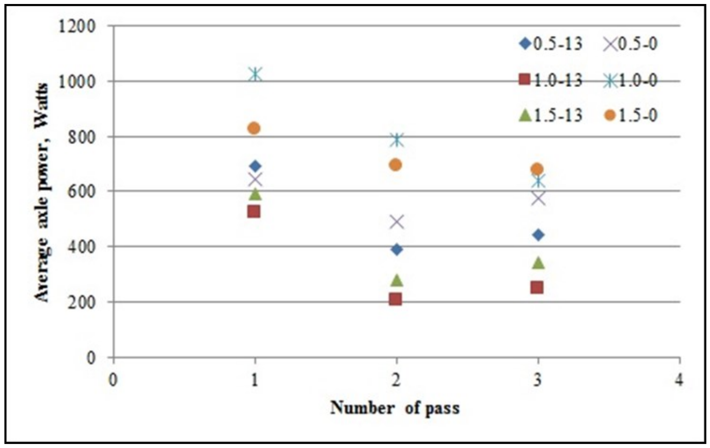

Figure 4. Average axle power with different lug angle (0° and 13°), forward speed (0.5, 1.0 and 1.5 km h^{-1}) and 250 rev min^{-1} shaft speed.

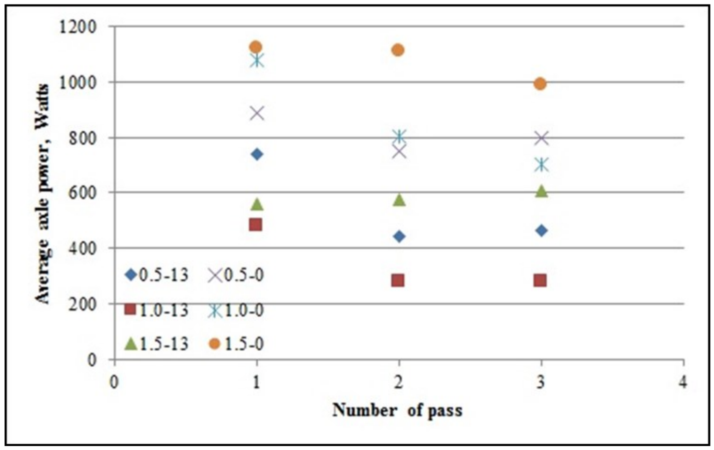

Figure 5. Average axle power with different lug angle (0° and 13°), forward speed (0.5, 1.0 and 1.5 km h^{-1}) and 300 rev min^{-1} shaft speed.

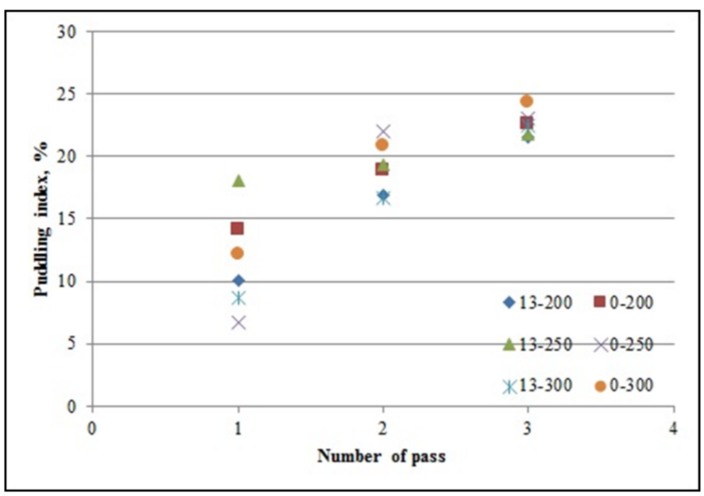

Figure 6. Puddling index with different lug angle (0° and 13°), shaft speed (200, 250 and 300 rev min^{-1}) and 0.5 km h^{-1} forward speed.

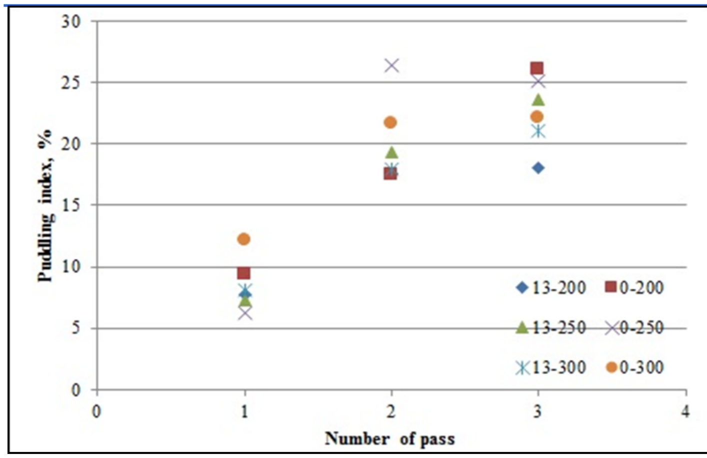

Figure 7. Puddling index with different lug angle (0° and 13°), shaft speed (200, 250 and 300 rev min^{-1}) and 1.0 km h^{-1} forward speed.

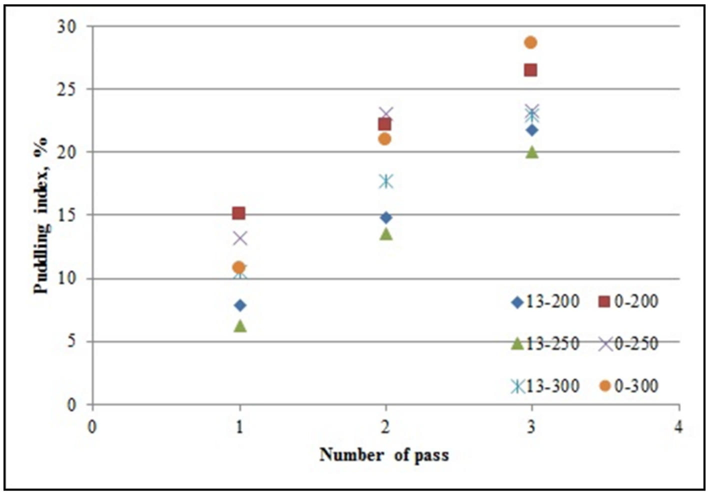

Figure 8. Puddling index with different lug angle (0° and 13°), shaft speed (200, 250 and 300 rev min^{-1}) and 1.5 km h^{-1} forward speed.

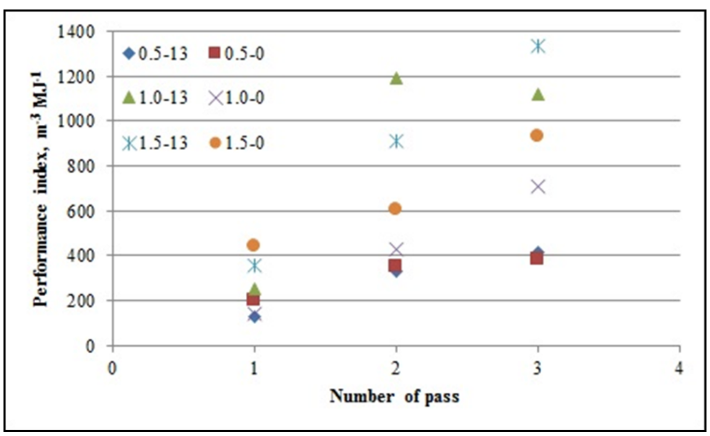

Figure 9. Performance index with different lug angle (0° and 13°), forward speed (0.5, 1.0 and 1.5 km h^{-1}) and 200 rev min^{-1} shaft speed.

axle power among shaft speeds were all significant. In the study by Fajardo *et al.* (2014), the mean differences of average drawbar power among passes were not significant between 1st and 3rd pass while mean differences between shaft speeds were also all significant.

Puddling Index at Two Lug Angles

Generally, puddling index increased as number of passes increased for all lug angles, forward and shaft speeds (Figures 6, 7 and 8). The highest puddling index was 28.6% with 0° on the 3rd pass at 300 rev min^{-1} and 1.5 km h^{-1} (Figure 8). The highest puddling index with 13° was 23.6% on the 3rd pass at 250 rev min^{-1} and 1.0 km h^{-1} (Figure 7).

Puddling index was significantly affected by the lug angle ($p=0.0000$) and number of passes ($p=0.0000$). In the study by Fajardo *et al.* (2014), puddling index is significantly affected only by the number of passes. Only the combination of lug angle and forward speed ($p=0.0098$) has significant effects on the average drawbar power. The mean differences of puddling index among passes were all significant.

Puddling Performance of Tilling Wheel at Two Lug Angles

Performance Index at Two Lug Angles

The performance index is the capacity of a tilling wheel in puddling soil with least power input. In general, higher performance index could be observed with 13° at 1.0 and 1.5 km h^{-1} (Figures 9, 10 and 11). For example, with 13° lug angle at 1.0 km h^{-1} and 250 rev min^{-1}, performance index has percent difference of 81% (on the average) with 0° at 1.0 km h^{-1} and 250 rev min^{-1}. The highest performance index was 1,334.6 m^3 MJ^{-1} on the 3rd pass with 13° at 200 rev min^{-1} and 1.5 km h^{-1} (Figure 9). The highest performance index with 0° was 933.35 m^3 MJ^{-1} on the 3rd pass at 200 rev min^{-1} and 1.5 km h^{-1} (Figure 9).

In general, performance index increased as number of passes increased for all lug angles, forward speeds and shaft speeds. On the 1st pass, the action of the tilling wheel was more of initial soil cutting and puddling; while during the 2nd pass, the action of the tilling wheel was more of puddling (wherein it needed less power input than soil cutting). Less power input would result to higher performance index. The average percent difference of performance index between 1st and 2nd pass was 117% at 250 rev min^{-1} with 13° and 0° lug angles and 0.5 and 1.0 km h^{-1}. The highest percent difference between 1st and 2nd pass was 148% with 13° lug angle at 250 rev min^{-1} and 1.0 km h^{-1}.

Performance index was significantly affected by the lug angle (p=0.0120), forward speed (p=0.0116) and number of passes (p=0.0116). In the study by Fajardo *et al.* (2014), performance index is significantly affected by the lug angle, number of passes and shaft speed. Only the combination of lug angle and forward speed (p=0.0305) has significant effect on the performance index. Performance index was not affected by the shaft speed and its combinations with other parameters was not expected for a rotating element such as the tilling wheel. Operation of a rotating element is set by the shaft speed. But the effect of shaft speed could be reflected through the forward speed setting in an actual set up. During an actual tilling operation, forward speed could be adjusted by adjusting the shaft speed of the tilling wheel. The mean differences of performance index among forward speeds were significant only between 0.5 and 1.0 km h^{-1}. The mean differences of performance index among passes were not significant between 2nd and 3rd pass. On the other hand, in the study by Fajardo *et al.* (2014), the mean differences of performance index among passes were not significant between 1st and 3rd pass.

Tractive Efficiency at Two Lug Angles

Tractive efficiency with 13° was relatively higher than with 0° lug angle at 1.0 and 1.5 km h^{-1} (Figures 12, 13 and 14). The highest tractive efficiency was 11.2% on the 1st pass with 13° at 200 rev min^{-1} and 1.5 km h^{-1} (Figure 12). The highest tractive efficiency with 0° lug angle was 7.9% on the 1st pass at 200 rev min^{-1} and 1.5 km h^{-1} (Figure 12). On the average, with 13° lug angle at 1.5 km h^{-1} and 200 rev min^{-1}, tractive efficiency has percent difference of 40% with 0° lug angle at 1.5 km h^{-1} and 200 rev

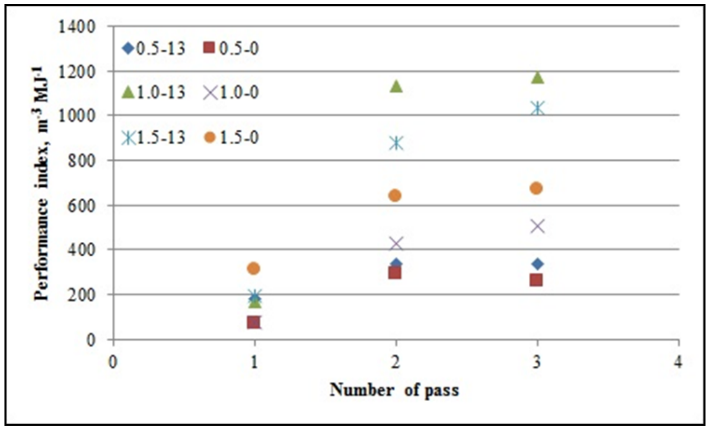

Figure 10. Performance index with different lug angle (0° and 13°), forward speed (0.5, 1.0 and 1.5 km h^{-1}) and 250 rev min-1 shaft speed.

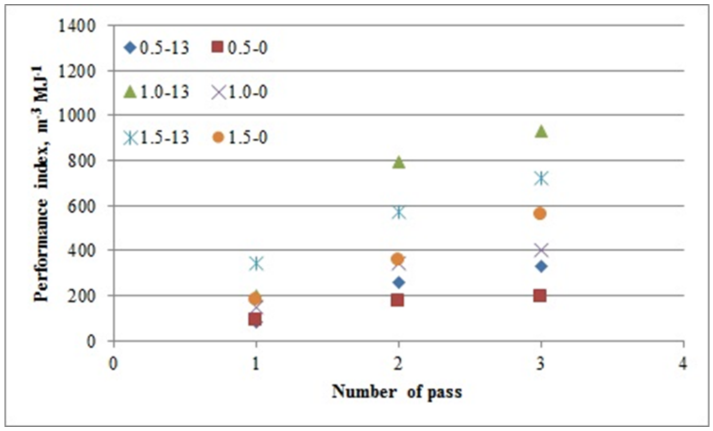

Figure 11. Performance index with different lug angle (0° and 13°), forward speed (0.5, 1.0 and 1.5 km h^{-1}) and 300 rev min-1 shaft speed.

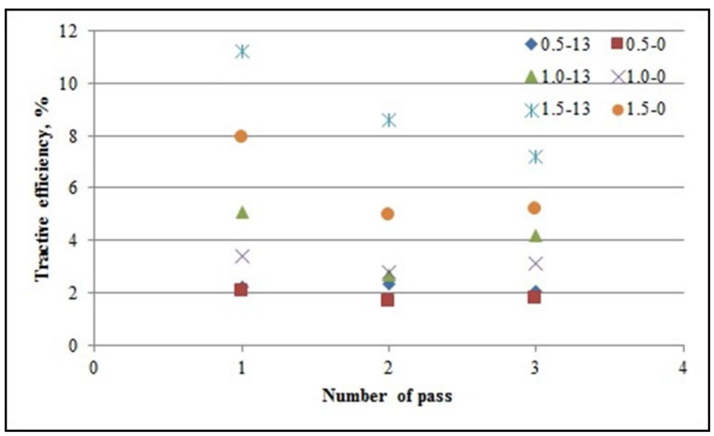

Figure 12. Tractive efficiency with different lug angle (0° and 13°), forward speed (0.5, 1.0 and 1.5 km h^{-1}) and 200 rev min^{-1} shaft speed.

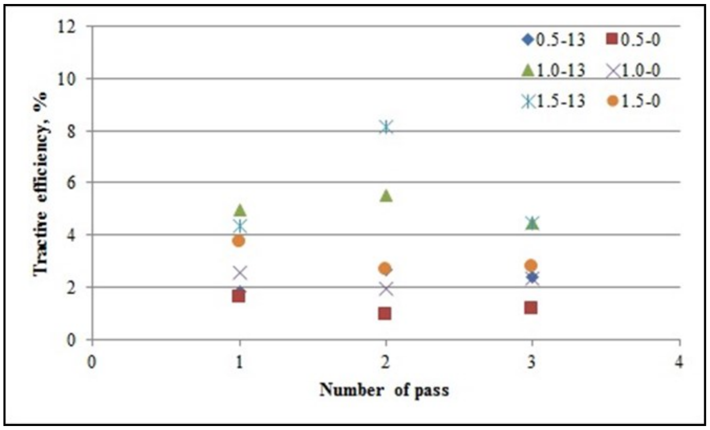

Figure 13. Tractive efficiency with different lug angle (0° and 13°), forward speed (0.5, 1.0 and 1.5 km h^{-1}) and 250 rev min^{-1} shaft speed.

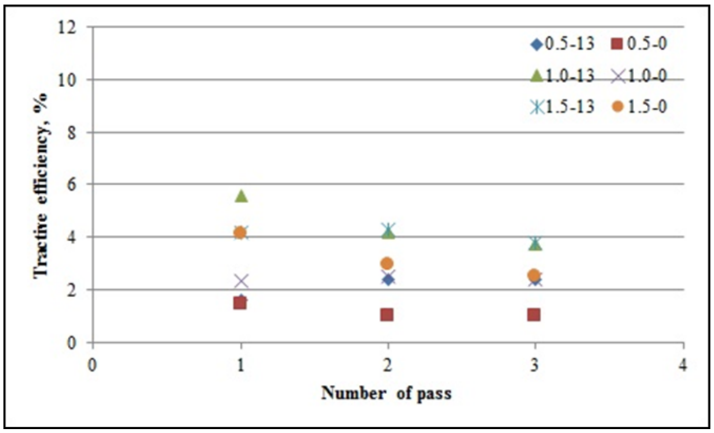

Figure 14. Tractive efficiency with different lug angle (0° and 13°), forward speed (0.5, 1.0 and 1.5 km h^{-1}) and 300 rev min^{-1} shaft speed.

min^{-1}. This is similar to the findings of previous studies (Gee-Clough and Chancellor, 1976; Pandey and Ojha, 1978; Gupta and Visvanathan, 1993; Hendriadi and Salokhe, 2002) that traction performance of cage wheels was better with higher lug angles. For example, in the study by Hendriadi and Salokhe (2002), results showed that increasing the lug angles from 15° to 35° and increasing the length of the lug improved the tractive performance of the cage wheel significantly.

Tractive efficiency was significantly affected by the lug angle (p=0.0028) and forward speed (p=0.0026). In the study by Fajardo *et al.* (2014), tractive efficiency is significantly affected by the lug angle and shaft speed. Again, results by Fajardo *et al.* (2014) were evaluated at 0.5 km h^{-1} only. Only the combination of forward speed and shaft speed (p=0.0387) had significant effect on the tractive efficiency. The tilling wheel is also the tractive device. At a given condition, forward speed will vary depending on the shaft speed. The mean differences of tractive efficiency among forward speeds were not significant between 1.0 and 1.5 km h^{-1}.

CONCLUSIONS

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

High performance index and tractive efficiency were obtained with 13° lug angle at forward speed of 1.0 and 1.5 km h^{-1}. Since the mean difference of tractive efficiency between 1.0 and 1.5 km h^{-1} was not significant, it is recommended to operate the tilling wheel with 13° lug angle at forward speed of 1.0 km h^{-1}.

Performance index was not affected by the shaft speed. On the other hand, only the combination of forward speed and shaft speed had an effect on the tractive efficiency. This was expected since the tilling wheel functions as tractive device and not just as puddling device.

The mean differences of performance index among passes were not significant between 2nd and 3rd pass. With this, the 3rd pass of a float-assisted tiller is no longer needed in an actual field operation with Maahas clay soil type to minimize cost.

RECOMMENDATIONS

The results obtained should still be verified in an actual field condition. Performance testing in an actual field condition may consider the effects of: float chamber design; land soaking condition; and presence of stubbles.

ACKNOWLEDGEMENT

The authors would like to acknowledge the support of the Center for Agri-fisheries and Biosystems Mechanization (BIOMECH, formerly AMDP), CEAT, UPLB in the conduct of this study.

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