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RESEARCH ARTICLE

Optimizing puddling efficiency: A comparative analysis of 13 and 16 hp power tillers in rice cultivation

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Abstract

Puddling is a critical soil preparation technique in rice cultivation, essential for creating a conducive environment that enhances water retention and nutrient availability in paddy fields. This study investigated the impact of power tiller horsepower and the number of passes on puddling effectiveness in alluvial clay soil under field conditions in Tamil Nadu, India. Two power tillers were evaluated: a 13 hp and a 16 hp model, using single, double and triple pass treatments. The 16 hp power tiller, launched in 2023, features a 16 hp engine, self-start capability and a ride-on design, while the 13 hp power tiller, available for around 20 years, is well-established. The results showed that the 16 hp power tiller consistently achieved higher puddling indices compared to the 13 hp model: 33.64 %, 45.22 % and 53.56 % for 1, 2 and 3 passes, respectively, versus 36.28 %, 43.78 % and 48.83 % for the 13 hp model. Similarly, the infiltration rate for the 16 hp model was significantly lower (2.17 mm, 1.67 mm and 1.25 mm for 1, 2 and 3 passes) compared to the 13 hp model (10.67 mm, 2.33 mm and 1.50 mm). This indicates superior soil compaction and reduced permeability with the 16 hp power tiller. Cost analysis revealed that the 16 hp power tiller is more cost-effective, with an operational cost, along with better fuel efficiency (0.075 L/hp/hr). The findings support the recommendation of using a 16 hp power tiller with two passes to achieve optimal soil conditions for rice cultivation, enhancing water management, productivity and cost efficiency in paddy fields.

Keywords: infiltration rate; power tiller; puddling; puddling index

Introduction

Puddling is an essential soil preparation technique in rice cultivation, primarily aimed at creating a soft, water-saturated soil bed that minimizes water percolation and enhances nutrient availability. This process involves mechanically manipulating wet soil to break down clods and create a uniform, puddled layer. The effectiveness of puddling significantly impacts soil properties, including bulk density, porosity and soil structure, which influence crop growth and yield (1-3). Thus, Puddling is a crucial technique in rice cultivation for enhancing water retention and improving yields, especially in water-scarce regions. However, it poses challenges for subsequent crops and requires careful management of water and energy resources. Exploring alternative methods and optimizing puddling intensity can help balance these benefits and challenges, contributing to sustainable agricultural practices.

Power tillers, particularly those with varying horsepower (hp), play a vital role in modern rice farming by providing efficient and consistent puddling. These machines are designed to perform multiple passes over the field, with each pass further refining the soil structure and enhancing the puddling effect. Using power tillers not only reduces the labor intensity associated with traditional methods and improves the precision and uniformity of soil preparation. Research has shown that different types of power tillers and their operational parameters, such as lug angle and shaft speed, significantly affect puddling performance and subsequent crop yield (4-6). This study aims to conduct a comparative analysis of the puddling performance of 13 hp and 16 hp power tillers under varying pass frequencies. By evaluating the impact of these variables on soil properties and rice yield, the research seeks to provide insights into optimizing puddling practices for enhanced agricultural productivity. The findings will contribute to developing more efficient soil management strategies, ultimately supporting sustainable rice cultivation (7-9).The objectives of the study are to evaluate the impact of different power tiller horsepower and the number of passes on the puddling index in paddy fields, assess the effects of puddling on soil infiltration rates and water retention capacity and focus on the formation of an impervious layer to improve water management. Additionally, the study aims to compare the operational efficiency, fuel consumption and cost-effectiveness of various power tillers used for puddling operations.

Materials and Methods

The experiment was conducted in the delta region of Tamil Nadu, specifically in Vannakudi Village near Tiruvidaimarudur in Thanjavur District. The exact coordinates of the field are 10.988050°N latitude and 79.462730°E longitude. This location was chosen for its suitability for the study. The soil type was alluvial clay and the experiment took place during the summer.The experiment began with direct puddling operations based on the designed treatments. The field was first flooded with 10-15 cm of water for 72 hr before puddling started. Two power tillers, i.e., the 13 hp (13 hp) and the 16 hp (16 hp), were used (Fig. 1). The specifications of the selected prime movers are provided in Table 1. A split plot layout was employed, with each treatment replicated three times and a randomization method used to assign treatments to plots to ensure unbiased results (Fig. 2). The treatments included single passes, double passes and triple passes. The rationale for using three passes in puddling operations stems from both traditional agricultural practices in Tamil Nadu and research findings that emphasize the benefits of multiple passes for optimal soil preparation. In Tamil Nadu, farmers typically perform two or more passes to achieve effective puddling, which is crucial for creating the right soil structure in flooded paddy fields. Previous studies have shown that additional passes enhance soil compaction, improve water retention and reduce permeability by forming a more refined and impermeable layer. Three passes, as used in this study, are seen as a balance between achieving ideal puddling conditions and maintaining efficiency. While additional passes further refine the soil structure, they also increase fuel consumption and operational costs. The single pass involved attaching a rotavator to each power tiller and operating at a consistent speed. The double passes treatment was conducted by repeating the single-pass procedure twice and the triple passes treatment involved repeating the single-pass procedure three times (treatments of the study in Table 2).

Table 1. Specification of power tiller

Specification	13 hp power tiller (13 hp)	16 hp power tiller (16 hp)
Engine Type	Horizontal 4 stroke single cylinder water, cooled diesel engine /OHV	Horizontal Single Cylinder, 4 Stroke, DI Diesel Engine
Engine Power	13 hp	16 hp
Fuel Consumption	1.25 ~ 1.5 L/hr	1.5 L/hr
Weight	405 kg	475 kg
Overall Dimensions (L x W x H)	2720 x 865 x 1210 mm	2870 x 1000 x 1540 mm
Transmission Type	Side drive rotary	Side drive
Tilling Depth	150 mm (maximum)	150 mm (maximum)
Tilling Width	600 mm (maximum)	750 mm max
Plough Depth	220 mm (maximum)	220 mm (maximum)
Number of tynes	18	22
Fuel Tank Capacity	11 L	14.3 L
Start Mechanism	Recoil starts	Electric start

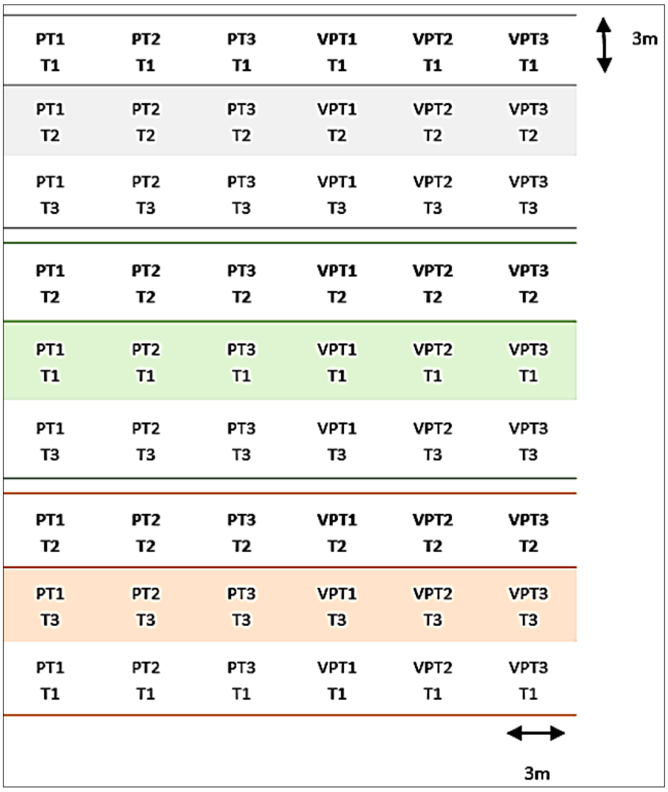

Fig. 2. Schematic of the block design used for field experiments.

Fig. 1. The prime movers used for the puddling operation. (a) 16 hp power tiller; (b) 13 hp power tiller.

Table 2. Treatments for the study

Treatments			
PT1	Power tiller 13 hp -1 pass	VPT1	Power tiller 16 hp - 1 pass
PT2	Power tiller 13 hp - 2 passes	VPT2	Power tiller 16 hp - 2 passes
PT3	Power tiller 13 hp - 3 passes	VPT3	Power tiller 16 hp - 3 passes

In 2023, the 16 hp power tiller was newly launched, featuring a 16 hp engine, self-start capability and a ride-on design. In contrast, the 13 hp power tiller has been well-established in the field for approximately 20 years. The objective of this study is to evaluate the puddling performance of these two power tillers and optimize their use for enhanced crop growth while simultaneously considering power consumption to ensure efficient use of energy. The findings aim to provide farmers with informed recommendations on selecting the most effective and efficient power tiller for their puddling practices.

Puddling index

The puddling index is a quantitative measure to assess the effectiveness of creating an impermeable layer in the soil, crucial for maintaining standing water in paddy fields. Standard procedures are employed to measure the puddling index, often complemented by evaluations of infiltration rate, penetration resistance and puddling depth. Puddling enhances soil conditions for rice cultivation by reducing soil strength, facilitating easier transplanting of rice seedlings and promoting better plant growth and yield potential, especially under drought conditions (10). Studies suggest optimizing puddling processes through adjustments in pass frequency and equipment selection to enhance the puddling index and overall soil conditions for improved rice cultivation (11, 12). The puddling index is determined using the formula:

$$Puddling\ Index = \frac{Vs}{V} \times 100$$

Once the final puddling process is complete, a 250 mL soil sample is taken using a graduated glass cylinder and allowed to settle undisturbed for 48 hr. The volume of the settled soil sample (Vs) is then measured, along with the initial volume (V) before settling (11, 13, 14).

Infiltration rate

The infiltration rate of the soil, which gauges the speed at which water penetrates and travels through the soil, is crucial in understanding soil water dynamics. Determining this rate is vital for evaluating soil permeability, irrigation efficiency and the potential for runoff (11). In the study, the infiltration rate in a paddy field after puddling was measured using a single-ring infiltrometer. The infiltrometer, along with a stopwatch, measuring scale and graduated cylinder, constituted the key materials used. A representative area of the field was selected, ensuring uniform soil conditions. The infiltrometer was positioned securely on the soil surface and inserted slightly to prevent lateral flow. Water was added to the infiltrometer to a specified level and water infiltration measurements were taken at regular intervals. Data collected were analysed to determine the average infiltration rate, essential for understanding soil water dynamics and optimizing irrigation practices in paddy cultivation. Understanding the infiltration rate is crucial for optimizing water management, minimizing water loss and ensuring sufficient water supply for rice crops, ultimately improving agricultural productivity and sustainability.

Statistical analysis

The statistical analysis for evaluating the effects of power tiller type (PM) and number of passes (PS) on puddling index and infiltration rate was conducted using a split-plot design and performed in R Studio software. Replications (REP) were treated as random effects, while PM and PS were considered fixed effects, with their interaction also assessed. ANOVA was conducted using the aov function, specifying the split-plot structure to partition variance into main effects, interactions and residuals.

Results and Discussion

Forming an impervious layer after effective puddling is a key factor in explaining the differences observed in puddling index and infiltration rates. During the puddling process, the soil particles are broken down and compacted, reducing pore space and leading to a denser, more uniform surface layer. This compaction creates an impervious layer at the soil surface, which significantly limits water movement and reduces infiltration rates. The resulting layer acts as a barrier, preventing excessive percolation and helping to maintain the necessary water levels for rice cultivation. The effectiveness of this impervious layer in controlling water retention is crucial for optimizing irrigation practices in paddy fields. As the number of passes increases, the compaction effect becomes more pronounced, resulting in better water retention and reduced infiltration, which is beneficial for maintaining consistent moisture levels throughout the crop cycle. Proper puddling not only enhances soil structure but also ensures more efficient water usage, contributing to improved crop yield and overall farming productivity. Therefore, forming an impervious layer is integral to achieving optimal puddling conditions and efficient water management in paddy fields.

Puddling Index

The study investigated the impact of power tiller horsepower and the number of passes on the puddling index, a crucial indicator of soil preparation effectiveness for rice cultivation. The results are summarized in Table 3.

The data demonstrates that the 16 hp power tiller consistently yielded a higher puddling index than the 13 hp power tiller across all pass numbers. This suggests that higher horsepower equipment is more effective in achieving thorough soil manipulation and creating a uniform puddled layer. Increasing the number of passes with 16 hp and 13 hp power tillers led to a noticeable increase in the puddling index. This trend indicates that multiple passes enhance soil structure

Table 3. Puddling Index (%) for different numbers of passes with 16 hp and 13 hp power tillers

No. of passes	Power tiller 16 hp	Power tiller 13 hp
1	33.64	36.28
2	45.22	43.78
3	53.56	48.83

refinement, potentially reducing clods and improving water retention capabilities. The 16 hp power tiller outperformed the 13 hp model due to its higher engine power, which provided greater torque for efficient soil manipulation and deeper penetration. Its advanced tyne configuration and heavier weight improved traction and clod breaking, enhancing the puddling index. These design features optimize soil preparation and water retention, ensuring improved performance in paddy fields comparatively.

At each pass increment, the 16 hp power tiller outperformed its 13 hp counterpart in achieving a higher puddling index. This disparity underscores the importance of equipment capacity and design in optimizing puddling efficiency. Farmers and agricultural practitioners can optimize puddling operations by selecting higher horsepower power tillers and conducting multiple passes. This approach not only improves soil conditions by reducing infiltration rates but also enhances water management efficiency in paddy fields. A study states that various equipment and techniques, such as cage wheels, rotavators and power tillers, impact the puddling index significantly. For example, a rotary tool-equipped power tiller achieved a notable 70.91 % puddling index in two passes (11, 14). Puddling effectiveness and resulting index vary with soil type. Different soil compositions, like silty loam versus sandy loam, respond uniquely to puddling techniques. A higher puddling index correlates with reduced infiltration rates, aiding water conservation by decreasing irrigation frequency during the crop cycle (15).

Infiltration rate

The infiltration rate readings reveal a notable difference between the performances of the 16 hp and 13 hp power tillers across different numbers of passes. Specifically, the 16 hp power tiller consistently maintained lower infiltration rates than the 13 hp model. The results are summarized in Table 4. These findings suggest that the higher horsepower of the 16 hp power tiller contributes to more effective soil compaction and reduced permeability during puddling operations. This improvement in soil water retention capability can potentially enhance the efficiency of water management practices in paddy fields, highlighting the practical advantages of using higher horsepower equipment in agricultural applications.

Various puddling techniques were evaluated to assess their impact on soil properties, particularly on infiltration rate. Techniques included using a power tiller with a rotary tool in two passes, a tractor-drawn cultivator with four passes and combinations of cage wheels and rotavators. The infiltration rate was measured using standard procedures in both laboratory and field conditions. The highest puddling index achieved was 70.91 %, with a corresponding infiltration rate of 6.5 mm/day using a power tiller with a rotary tool in two passes (3). The depth of puddling was varied, with deeper puddling (10-12 cm) showing a significant reduction in infiltration rate compared to shallower depths. Fine-textured soils like silty loam exhibited greater reductions in infiltration rate with increased puddling intensity, particularly in soils with higher organic matter content (16).

Table 4. Infiltration rate (mm) for different numbers of passes with 16 hp and 13 hp power tillers

Number of passes	Power tiller 16 hp	Power tiller 13 hp
1	2.17	10.67
2	1.67	2.33
3	1.25	1.50

Statistical analysis

The ANOVA results (Tables 5 and 6) show that Prime Mover (PM) and Passes (PS), along with their interaction (PM), significantly influence the response variable. The F values for PM, PS and PM are 54.287, 58.414 and 41.684, respectively, with p-values of 2.40e-05, 3.05e-06 and 1.41e-05, all below 0.05. This highlights the importance of considering both the type of prime mover and the number of passes and their interaction in experimental design.

Cost of operation

The cost of operation analysis for different prime movers emphasizes their operational efficiency and suitability for various farming scales, clearly distinguishing between the two power tillers evaluated. The Power Tiller 16 hp is the most cost-effective and fuel-efficient, with an operational cost of Rs 362.51/hr and Rs 1176.96/ha. Its fuel efficiency of 0.075 L/hp/hr makes it an excellent choice for small to medium-scale farming operations. It balances power, fuel efficiency and overall cost, particularly for tasks like puddling and tilling. In contrast, the Power Tiller 13 hp, while having a lower initial investment, results in higher operational costs, especially on a per-hectare basis of Rs 2422.40/ha, due to its lower horsepower and higher fuel consumption, besides more number passes of puddling was required to attain the optimized soil condition for paddy, thus the cost of operation was high comparatively. This makes the 16 hp power tiller the more economical choice for farming tasks that require both power and cost-effectiveness, demonstrating that investing in higher horsepower can lead to significant long-term savings and enhanced productivity.

Conclusion

Based on the results, while increasing power tiller horsepower and the number of passes improves puddling quality, optimizing these factors to avoid unnecessary energy consumption and economic inefficiencies is crucial. The study highlights that achieving effective soil manipulation and a uniform puddled layer can be efficiently accomplished with two passes using a 16 hp power tiller, which consistently outperformed the 13 hp model in puddling effectiveness and

Table 5. ANOVA Results for puddling index

Source	*Df*	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
REP	2	147.7	73.8	3.451	0.072488.
PM	1	6.2	6.2	0.29	0.60194
PS	2	798.5	399.2	18.66	0.000421 ***
PM:PS	2	40.9	20.4	0.956	0.417047
Residuals	10	214	21.4		

Table 6. ANOVA results for infiltration rate comparison based on number of passes and power tiller type

Source	*Df*	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
REP	2	1.82	0.91	1.166	0.351
PM	1	42.32	42.32	54.287	2.40e-05 ***
PS	2	91.07	45.54	58.414	3.05e-06 ***
PM:PS	2	64.99	32.5	41.684	1.41e-05 ***
Residuals	10	7.8	0.78		

water retention. This approach not only enhances soil conditions by reducing infiltration rates but also supports improved water management in paddy fields. Therefore, for optimal results in rice cultivation, farmers are encouraged to consider the practical balance between power availability, operational efficiency and economic feasibility when selecting and utilizing power tillers for puddling operations. The 16 hp power tiller is most suitable for small to medium farms, offering a cost-effective solution with balanced power and fuel efficiency. The 13 hp power tiller, though ideal for small farms, has a higher cost per hectare due to its lower power and fuel efficiency.

Future recommendations

As a future recommendation, testing these findings under varying soil types, such as sandy loam, clay and loamy soils, would provide deeper insights into the performance of the power tillers across different soil textures. From a future perspective, developing a machine learning model for real-time bulk density monitoring while puddling would enhance soil management by offering continuous feedback, allowing operators to make immediate adjustments for optimal soil preparation, ultimately improving water conservation, soil health and overall agricultural sustainability.

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Authors' contributions

All authors have contributed equally to the conception, design and execution of this research study.

Compliance with ethical standards

Conflict of interest: The authors declare that there is no conflict of interest regarding the publication of this paper.

Ethical issues: None

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