Performance of lugged cage wheel for wetland cultivation

Arvind Kumar[*1], D.C. Baruah[2]

(1. Division of Agricultural Engineering, ICAR Research Complex for NEH Region, Umiam, Meghalaya, India – 793103;
2. Department of Energy, Tezpur University, Tezpur, Assam, India -784028)

Abstract: Rice is a major food grain crop grown in North-eastern Himalayan region of India with varying level of mechanization. Rice field remains wet and loose for a considerable period of growing season. Land preparation of rice field is one of the critical operations both in terms of timeliness and energy requirement. The losses up to 70%-80% of input power are reported while negotiating wetland terrain by tractors or power tillers, particularly in difficult terrain. This paper described the attempts made to address the issue of wetland traction primarily relevant to mechanization of rice cultivation in North-eastern Himalayan region of India. There is a variety of design of cage wheels used on power tillers with varying levels of performances based on the soil conditions. An innovative lug of split type has been developed, tested and compared with non-split lugs of identical contact area in the sandy loam soils of wetland rice fields of the region. Cage wheel lugs interact with the soil and thrust is generated to move the power tiller forward. The strength of supporting soil and area of contact governs the generated thrust. In general, the pull developed by cage wheel is positively correlated with area of interaction especially in better soil condition. Release of loose soil trapped beneath the cage wheel lugs, so as to bring hard layers of soil in contact with the interacting lug surface, is attempted through split lugs instead of solid lugs (non-split). A set of lugs with split (S) and non-split (NS) having 3 varying sizes (8000, 12000 and 16000 mm2 surface area) were fabricated as per suitability of a typical walking type tractor (power tiller). Each set of lugs were fitted on cage wheel frame at 450 angular spacing for testing its field performance at two levels of soil moisture contents (23% and 36%). During experiments the performance enhancement of split lugs was found better in moist (36%) soil than a relatively dry (23%) soil. Newly designed lug fitted power tiller operation resulted higher (0.052 ha/h) field capacity (about 17% higher than the identical non-split lug). The fuel consumptions of split lugs were found less compared to non-split lugs of all sizes. Split lug cage wheel fitted power tiller operation resulted about 27% less wheel slip associated with about 14% saving of fuel (L/ha) in comparison of non-split lug in moist field.

Keywords: split lug, cage wheel, wetland cultivation, wheel slip, field capacity

Citation: Kumar, A., and D.C. Baruah. 2016. Performance of lugged cage wheel for wetland cultivation. Agricultural Engineering International: CIGR Journal, 18(3):113-118.

1 Introduction

Rice (*Oryza Sativa L.*) is one of the most important cereal food crops of India occupying about 24% of gross cropped area of the country. It contributes 42% of total food grain production and 45% of total cereal production of the country. Rice is also the principal food crop of the North Eastern Region of India occupying an area of about 3.5 m ha with an average productivity of 1.77 t/ha which is much below the national average. The region has faced a deficit of about 2.8% food grains in 2010-11 (Das Anup et.al. 2012).Movement of machine over wet and loose terrain involves difficulties associated with higher level of energy consumption. Rice is a major food grain crop grown in different parts with varying level of mechanization. To utilize the benefits of mechanization, improved and appropriate energy conservation devices are prerequisite. This is more relevant for mechanization of typical wetland rice fields of Southeast Asia including India. Low conversion of engine power of tractors and power tillers into useful work makes the mechanization of wetland cultivation energy inefficient.

Different types of traction devices or cage wheels have been designed and are used in different parts of the world. These are designed for a particular working conditions and their efficiency is still low. In firm good

Received date: 2016-05-11 **Accepted date:** 2016-06-15
***Corresponding author: Arvind Kumar,** Division of Agricultural Engineering, ICAR Research Complex for NEH Region, Umiam, Meghalaya, India – 793103. Email: arvindkr30@yahoo.com

soil condition the traction can be improved significantly just by adding more weight to the tractor drive wheel. In wet loose soil condition the internal friction ($\emptyset$) is very low, therefore the increase in weight on the drive wheel does not increase traction effectively unless the traction device can displace the loose surface soil and get support on comparatively firm soil. Therefore, a traction device (cage wheel) having special lugs is required for better traction in wetland.

A number of research work have been done on wetland traction such as (i) performance analysis of cage wheels operated in wetland (ii) behaviour of soil under the action of traction device (iii) new designs of wetland traction devices (iv) traction dynamics study and (v) optimization of design parameters of traction aid (Kumar A and Baruah DC, 2013). Circumferential lugs provided in the cage wheel assists in traction. Experiments conducted on tractive performance of cage wheels affected by opposing circumferential lugs, lug spacing and wheel slip concluded that the peak power of the cage wheel reached at about30%-40% wheel slip depending on the circumferential angle and lug spacing. The modified wheels with 15^0 circumferential angles at 24 and 30^0 lug spacing showed significantly higher tractive power compared to other combinations. Finally considering the performance and cost of materials, the cage wheel with opposing circumferential angled lugs at 15^0 circumferential angle and 30^0 lug spacing was recommended for power tillers in Thailand (Watyotha and Salokhe, 2001).In a study on effectiveness of a cage wheel used with driving tires in wet paddy fields showed that the traction performance of the tractor increased with the increase in diameter of the cage wheel. About 36% to 43% of the total torque was used by the cage wheel with diameter 1182 mm and 49% to 56% when it increased to 1222 mm. The peak torque required by a single lug increased by 5% as the diameter increased from 1182 to 1222 mm and by 17% as it increased to 1262 mm. The peak traction also increased by 31% and 59%, respectively, at the same increases in diameter (Wu et. al., 2004). Such studies provided useful information for designing traction aids, especially lugs of cage wheel. However, in majority of the cases optimal design parameters of traction aids are decided based on either the experimental results concerning some fixed set of system parameters or optimal values obtained from statistically analysed results of experiments. This necessitates further research work aiming to develop effective analytical tool for wetland traction.

The optimal design of lugs with reference to its geometry and spacing has been a major area of investigation. Therefore, attempt to reduce losses would lead to conserve precious energy. This paper describes a new traction aid for improvement of wetland traction with a goal to conserve energy and contribute positively for the much needed rice field mechanization. Release of loose soil trapped beneath the cage wheel lugs, so as to bring hard layers of soil in contact with the interacting lug surface, is attempted through split lugs instead of non-split lugs. A set of split and non-split lugs with varying sizes are designed, fabricated and fitted on power tiller cage wheel and tested for its feasibility in field at two different moisture conditions.

2 Methodology

The experiments were conducted at the research farm of ICAR Research Complex for NEH Region, Umiam, Meghalaya, India (25^0 41' N latitude and 91^0 55' E longitude) during 2013-2015. The cage wheel fitted with six different newly designed lugs; two types (split-S, and non split- NS) having three different surface areas of 8000 mm^2 (S8 and NS8), 12000 mm^2 (S12 and NS12) and 16000 mm^2 (S16 and NS16) were evaluated in the field condition (Figure 1) using a commercially available power tiller.

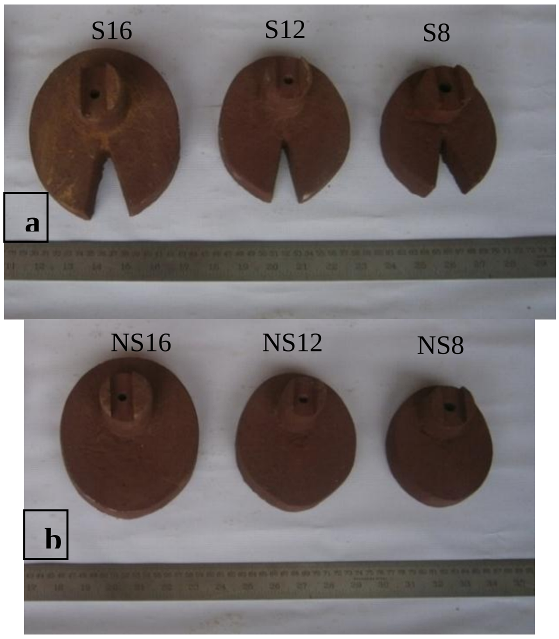

Figure1 (a) Split lugs -S and (b) Non split lugs- NS

The power tiller used for test is equipped with 6.7 kW diesel engine, 6 forward, 2 reverse speeds and 600 mm tilling width (Figure 2).The conventional cage wheel having 700 mm diameter was modified by welding square bar of 12 mm size in between the spokes to enable the fixing of newly developed lugs. Holes were drilled in the welded square bar and lugs were mounted with the help of bolts. The orientation of lugs on the cage wheel is such that the split portion of lug is in the direction of forward movement of cage wheel. Total 8 numbers of lugs on each cage wheel were fitted for each test.

Figure 2 Power tiller fitted with cage wheel having newly developed lugs

The field was initially ploughed twice with power tiller operated rotavator under dry condition and flooded with water for saturation. The cone penetrometer was used to determine the cone index before testing the cage wheel. Measured cone index values are given in Table 1. Soil samples were collected and analyzed for soil physical properties (Table 2). Power tiller fitted with newly developed cage wheel was operated in the field. Each test was replicated thrice at two field conditions viz., (a) soil moisture content of 23.5% and (b) soil moisture content of 36% with each lugged cage wheel. Rate of fuel consumption was recorded with a special arrangement of recording the volume of diesel fuel consumption during a measured time interval of experiment. Similarly, speed of operation, cage wheel slip and width of coverage were estimated from the field experiment data recorded using standard procedure. Finally, wheel slip, (%), field capacity (ha/h) and rate of fuel consumption (L/ha) estimated for each test conditions are compared between spilt and non-spilt lugs. The changes of performance parameters of split lugs in relation to non-split lugs were determined for both the field conditions. To compare the effects of different design parameters on field performance, the observed field test data are statistically analyzed using Duncan's Multi Range Test (DMRT).

Table 1 Cone index of field soil using 5 cm^2 cone

Depth, cm	36% moisture		23.5% moisture	
	Dial reading, N	Cone resistance, kPa	Dial reading, N	Cone resistance, kPa
5	0	0	40	80
10	30	60	110	220
15	90	180	240	480
20	480	960	580	1160
25	540	1080	590	1180

Table 2 Soil physical properties of test field

Soil type	Sandy loam
Average soil moisture content of two test field conditions	23.5% and 36% d.b.
Soil bulk density	17.73 kN m^{-3}
Mean weight diameter, MWD	2.21 mm
Macro aggregates (aggregate >1.0 mm):	60.69%
Micro-aggregates (aggregate >0.25 mm and <1.0 mm):	29.68%

3 Results and discussion

The effects of lug split and lug area on field performances for two different soil conditions are presented and discussed below. The percent changes in performance parameters of split lugs over non-split lugs are also estimated and presented in Section 3.3.

3.1 Effect of lug split on rate of field coverage

The test results of field capacity (ha/h) of 6 different lugs in two different field conditions (23.5% and 36% soil moisture) are presented in Figure 3. The field capacity is increasing with the increase in surface area of both split and non-split lugs. This is due to the decrease in slip with increasing lug area (Table 3).

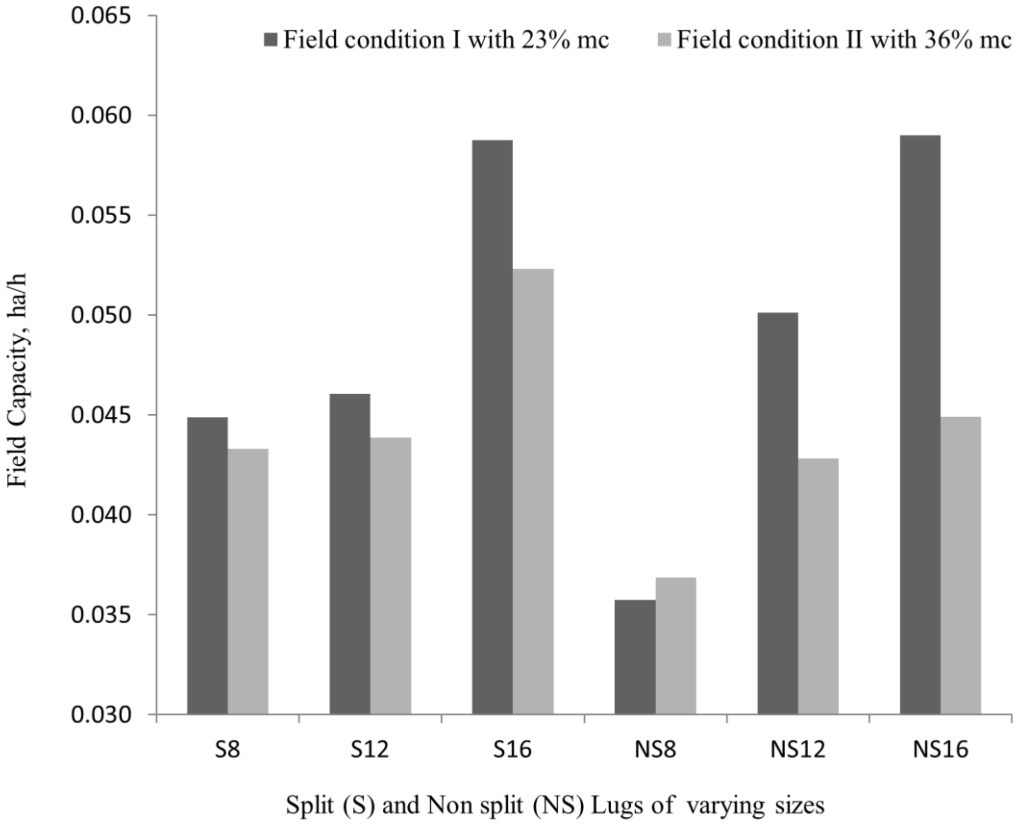

Figure 3 Field capacity of six different lugs at two different field conditions

Table 3 Effect of different lug design on field capacity

Lugs	Field Capacity
S8	0.043^{cd}
S12	0.043^{cd}
S16	0.053^{b}
NS8	0.036^{d}
NS12	0.048^{bc}
NS16	0.051^{b}

Note: Means with the same letter are not significantly different

Table 3 shows the pooled effect of lug design on field capacity as there was marginal difference between two different soil moisture contents. This may be due to less difference in two soil moisture conditions. There is significant difference in field capacity of split and non-split lugs except for larger size lug. The larger size lug (S16) has also shown gain in field capacity as compared to NS16, but statistically none significant, which may be due to larger surface area of lug.

Overall the split lug has shown positive effect on field capacity at higher moisture content and is higher than the non-split lugs of same contact area for all sizes. At lower soil moisture content, split lug (S8) resulted higher field capacity than non-split lug (NS8) having same area. However, there is no significant difference in field capacity of S16 and NS16 at lower moisture. At higher moisture condition all the split lugs exhibited higher field capacity than non-split lugs having identical surface area. The benefit of split is realized with higher moisture field for which this lug is intended. Thus, the reflection of varying level of traction performance could be seen as varying level of field capacity which is attributed by design parameters. Comparing the field capacity results, the split lug with higher area is expected to provide more benefits in high moisture soils.

3.2 Effect of lug split on wheel slip

Results of wheel slip of six different types of lugs at two levels of soil moisture conditions are shown in Figure 4 and Table 4.Earlier investigation has shown that the slip decreases with increase in surface contact area of lugs (Hendriadi and Salokhe, 2002). Same trend was seen in this investigation with split and non-split lugs.

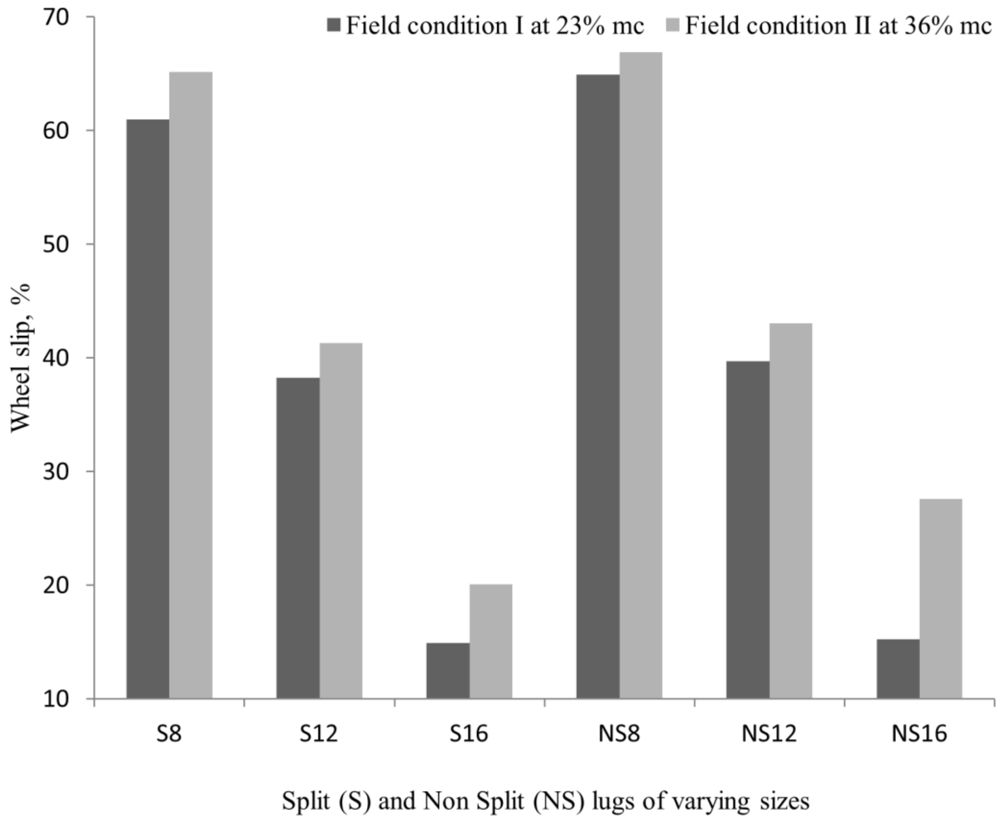

Figure 4 Cage wheel slip at two different soil moisture conditions

Table 4 Effect of lug design on wheel slip in two different field conditions

Lugs	Field Condition	
	I (23.5% moisture content)	II (36% moisture content)
S8	60.97[a]	65.11[a]
S12	38.25[b]	41.27[b]
S16	14.89[c]	20.04[cd]
NS8	64.90[a]	66.87[a]
NS12	39.69[b]	43.01[b]
NS16	15.24[c]	27.55[c]

Note: Means with the same letter are not significantly different

Statistically there is no significant difference in wheel slip of split and non-split lugs in two different field conditions. However, the Table 5 indicates the advantage of split lug over non-split lug in terms of wheel slip. Slip has decreased for all split lugs compared to non-split lugs of identical area for both field conditions. This may be due to the reason that loose soil is escaped through the split in lug and getting better support from comparatively more stable soil.

The maximum reduction of wheel slip in respect of non-split lug was 27.3% for S16 lug at 36% moisture content, whereas minimum reduction was 0.41% for S16 at soil moisture content of 23.5%. Thus, the split lug of larger size is showing better result in terms of slip at higher moisture field. Therefore, similar to the results of field capacity, the improvement of wheel slip through split lug is more prominent under high moist field than relatively dry field.

3.3 Overall comparison of split and non-split lugs

It is seen from Table 5 that the fuel consumption (L/ha) at higher moisture content (36%) has decreased for split lugs as compared with non-split lugs of same area for all the three lugs. Decrease is more for S8, followed by S16 and S12 respectively. This reduction in fuel consumption is achieved due to reduced slip and increased field capacity by using split lugs. Therefore, the positive effect of split lugs is reflected in terms of fuel saving compared to identical size non-split lugs at higher soil moisture condition. Thus, larger size split lug is expected to reduce the energy consumption for field operation under wetland conditions. However, at lower soil moisture the saving in fuel consumption per unit area is not seen except for S8 lugged cage wheel.

Table 5 Percent changes in performance parameters of split lug (S) over non split lug (NS)

Treatments	Field Condition I (23.5% mc)				Field Condition II (36% mc)			
	Linear Speed	FC	Slip	Fuel consumption	Linear Speed	FC	Slip	Fuel consumption
S8	25.53	25.53	-6.04	-22.23	17.49	17.49	-2.61	-16.66
S12	-8.13	-8.13	-3.65	5.93	2.45	2.45	-4.05	-2.60
S16	-0.41	-0.41	-2.30	4.59	16.53	16.53	-27.3	-13.67

4 Conclusions

The specific conclusions drawn from the present study are given below.

4.1 The area of contact and lug shape plays significant role on traction performance. Larger size split lug results the higher field capacity in comparison to smaller size non-split lugs operating in wetland.

4.2 Reduction of wheel slip and associated diesel saving (up to 16%) is expected while operating a power tiller fitted with split lugged cage wheel over non-split lugged cage wheel in moist soil.

Acknowledgements

Authors are highly thankful to the Director, ICAR Research Complex for NEH Region, Umiam for providing necessary facilities to carry out the research work at the institute research farm.

References

Das Anup, D.P. Patel, G.I. Ramkrushna, G.C. Munda, S.V. Ngachan, B.U. Choudhury, K.P. Mohapatra, D.J. Rajkhowa, R. Kumar, and A.S. Panwar. 2012. Improved Rice Production Technology for resource conservation and climate resilience (Farmers' Guide). *Extension Bulletin No. 78*. ICAR Research Complex for NEH Region, Umiam, Meghalaya.

Hendriadi, A., and V. M. Salokhe. 2002. Improvement of a power tiller cage wheel for use in swampy peat soils. *Journal of Terramechanics,* 39(2):55-70.

Kumar A., and D. C. Baruah. 2013. Wetland traction research: present status and future need. *International Journal of Agricultural Engineering,* 6(1):216-220.

Watyotha, C., and V. M. Salokhe. 2001. Tractive Performance of Cage Wheels with Opposing Circumferential Lugs. *Journal of Agricultural Engineering Research*, 79(4): 389-398.

Wu, Y., K. U. Kim, B. H. Chong, and J. Piao. 2004. Effectiveness of a Cage wheel as a Traction Aid. *Transactions of the ASABE,* 47(4): 973-980.

Watyotha, C., D. Gee-Clough, V. M. Salokhe. 2001. Effect of circumferential angle, lug spacing and slip on lug wheel forces. *Journal of Terramechanics,* 38(1):1-14.

Watyotha, C., and V. M. Salokhe. 2001. Pull, lift and side force characteristics of cage wheels with opposing circumferential lugs. *Soil and Tillage Research,* 60(3-4):123-134.